

Master Beekeeper Certification Study Guide

Master Level — Aligned to the Separate 365-Question Mock Examination, Ver. 2.3

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EASTERN APICULTURAL SOCIETY MASTER BEEKEEPER

A NOTE TO THE READER

This document may be freely distributed in its original form.

This document is a result of organizing and researching many online resources, combined with study materials from conferences, reading lists, as well as presentations made by me to local groups and at State conferences.

To assist in the creation of this Master Beekeeper Certification Study Guide, A.I. has been used. A word of warning, while A.I. is great at organizing and managing information, it can make mistakes, sometimes convincingly. The core information contained here has been passed through A.I. multiple times to confirm the validity of the information however it is up to the reader to double-check the facts contained here. Additionally, science changes. What was once an accepted fact becomes dated and replaced by newer scientific discoveries. Accepted treatments change, approved treatments are replaced or outlawed. Therefore, the reader, as a prospective Master Beekeeper, should always perform due diligence to ascertain the validity of any information contained here.

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Preface

This guide is written for the experienced beekeeper preparing for master-level certification. Every chapter is built on a single premise: the Master Beekeeper examination tests *why*, not just *what*. Memorizing that the Varroa treatment threshold is 2 percent in late summer will not carry a candidate through an item that asks why the late-summer count, more than any other, decides whether a colony survives the winter. This guide supplies the mechanism behind every number, threshold, and recommendation it presents.

The twenty chapters follow the domain structure of the separate mock examination, covering questions Q1 through Q365. Each chapter opens with an orientation that names the two or three ideas that organize everything else, moves through connected expository prose explaining the underlying science and craft, and closes with a “Numbers to Know Cold” table, a “Common Misconceptions” section drawn from the errors that appear as examination distractors, self-check questions with model answers, and a curated further reading list.

Regional conventions throughout: this examination avoids state names in body text. The guide follows that convention. The southeastern United States, the coastal plain, the piedmont, the southern Appalachian mountains, the Gulf coastal areas, and the river swamps are the physiographic terms used. State extension services and named research institutions appear only in the Further Reading sections, where a reader cannot look up a generic citation.

A word on currency: the facts in this guide reflect the best available knowledge as of October 2026. The Honey Bee Health Coalition’s *Tools for Varroa Management*, 9th edition, released 22 June 2026, is the current standard for Varroa thresholds and product guidance. A 2026 study that found the Y215H amitraz-resistance mutation in every mite it screened from commercial operations is incorporated throughout the Varroa and IPM chapters, because a candidate who is unaware of this finding is unprepared for the examination and, more importantly, unprepared for the field.

Chapter 1. Honey Bee Biology, Anatomy & Physiology

Covers exam questions Q1-Q27.

1.1 Orientation

Everything else in this guide rests on this chapter. A master-level candidate is not asked whether she can recite that a worker emerges on day twenty-one. She is asked why a queen cell is capped on day eight, and therefore why a seven-day inspection interval is the standard in swarm season, and therefore why the beekeeper who inspects every ten days loses swarms she never saw coming. The exam builds its items out of chains like that.

Three ideas organize the material. The first is **plasticity**. One genome produces a queen or a worker, a nurse or a forager, a six-week summer bee or a six-month winter bee, and in every case the switch is thrown by nutrition and hormonal state rather than by genetics. Wherever the exam offers "genetically determined" or "a fixed developmental clock," that is almost always the distractor.

The second is **constraint**. Hemolymph carries no oxygen, so gas exchange is local. The crop is a transport vessel, not a stomach, which requires a valve to keep it that way. The rectum has finite capacity, so what cannot be digested must be held. The spermatheca is filled once and never refilled. Each constraint generates a predictable failure mode, and the exam likes to approach the constraint through the failure.

The third is **physiological state as a readout of colony condition**. Hypopharyngeal glands, fat body volume and circulating vitellogenin record what nutrition and parasite load did to a bee in her first days of adult life. This is why a colony can look populous in October and be dead in February, and why the late-summer mite count is the most consequential number of the beekeeping year.

1.2 Sex, Caste and the Developmental Timetable

1.2.1 Haplodiploidy and the sex locus

Honey bees are haplodiploid. An unfertilized egg is haploid and becomes a drone; a fertilized egg is diploid and becomes a female. The proximate mechanism is a single complementary sex-determination locus, *csd*, carrying many alleles in wild populations. Heterozygous at that locus means female; a single copy, as in a haploid, means male. Sex is decided by heterozygosity, not by ploidy as such.

That distinction produces the case the exam wants. A fertilized egg can be diploid and still homozygous at *csd*, if the queen mated with a drone carrying an allele she also carries. Such an egg becomes a **diploid drone**, and nurse bees detect and cannibalize the larva within a few hours of hatching. The cell is emptied before the beekeeper sees anything in it.

The field result is the scattered "shot" brood pattern of an inbred colony: the queen is laying normally, the eggs are hatching, and the larvae are removed too fast to see. The diagnostic picture is a spotty pattern with no other findings - no odor, no ropiness, no scales, no sunken or perforated cappings, negligible mite counts, and eggs in normal distribution. In a mating sharing one allele, half the fertilized

eggs are homozygous, so the loss is severe. Requeening from the same line will not fix it; the remedy is unrelated genetics.

1.2.2 Caste is nutritional

Queen and worker arise from identical fertilized eggs. What separates them is the quantity, composition and duration of larval feeding. A worker larva is fed progressively, on a jelly that shifts after about three days toward honey and beebread. A queen larva is fed copiously and continuously on royal jelly richer in sugars and in the mandibular-gland lipid fraction, and is never put on short rations. The higher sugar content drives higher feeding rates, which raises larval juvenile hormone, which preserves ovarian tissue otherwise destroyed by programmed cell death in the worker.

The differences are structural and permanent. A queen carries roughly 100 to 180 ovarioles per ovary, a median near 320 in total in one survey of commercial queens; a worker carries a few per ovary, typically two to twelve, and no functional spermatheca. The queen also develops faster, sixteen days against twenty-one.

Because caste depends on how long the larva receives queen-type feeding before the pathways diverge, **larval age at grafting is the largest controllable determinant of queen quality**. Larvae grafted under twenty-four hours old yield queens with more ovarioles, larger spermathecae and higher emergence weight; queens started from larvae older than about three days are measurably inferior on all three, A colony raising an emergency queen usually chooses young larvae, but if none are present it will build over older ones, and the resulting queen is inferior. Where certainty ends: royalactin was proposed as the queen-determining royal jelly protein and parts of that work have failed to replicate, while a competing account emphasizes p-coumaric acid and other beebread compounds that alter DNA methylation in worker-destined larvae. Both agree on what the exam tests - the signal is dietary.

1.2.3 The timetable

Stage	Queen	Worker	Drone
Egg	3 days	3 days	3 days
Larva, feeding	about 5.5 days	about 6 days	about 6.5 days
Cell capped on day	about 8	about 9	about 10
Capped period	about 8 days	about 12 days	about 14-15 days
Emergence	day 16	day 21	day 24

Memorize the capping days alongside the emergence days, because capping drives management. A queen cell is capped about day eight and a prime swarm usually issues at or shortly after capping, so a seven-day round guarantees no cell can go from egg to capped between visits. A ten-day round does not.

Capped duration drives parasite biology. A drone cell stays capped about fourteen to fifteen days against twelve for a worker. Because *Varroa destructor* begins laying only after a fixed delay from capping and at fixed intervals thereafter, those extra days let substantially more offspring mature - on

the order of two to two and a half viable daughters per drone cell against a bit over one per worker cell. That arithmetic explains the mite's preference for drone brood and why drone brood trapping works.

Larvae pass through five instars; the fifth spins a cocoon, voids its gut for the first time and becomes a prepupa. A worker larva is visited by nurses on the order of 1,300 times a day, more than 10,000 times over her larval life, most of those visits being inspections rather than feedings, which is the real measure of what brood rearing costs in nurse labor and protein.

1.3 Age Polyethism: A Default, Not a Schedule

A worker's life follows a broad sequence: cell cleaning for two or three days; brood warming and nursing from roughly day three to twelve; receiving nectar, packing pollen and building comb from roughly day twelve to eighteen; undertaking and guarding around days eighteen to twenty-one; foraging from about day twenty-one until death at four to six weeks, with the foraging phase lasting one to two weeks as wings and flight muscle wear out.

The sequence is a **default produced by hormonal state interacting with colony demand**, not a clock. Two results define its flexibility. Strip a colony of foragers and young bees forage precociously, some as early as seven days old. Strip it of nurses and foragers revert, redeveloping their hypopharyngeal glands and resuming brood care. Neither is possible under a fixed schedule, and neither is explained by foragers recruiting individual house bees.

The machinery is mutual repression between vitellogenin and juvenile hormone. Young bees carry high vitellogenin and low juvenile hormone; as vitellogenin is spent making brood food the repression lifts, juvenile hormone rises, and the bee transitions to foraging. Because vitellogenin is spent by nursing and replenished by eating pollen, the system is coupled directly to what the colony is doing and what it has to eat. Demand is also transmitted chemically: returning foragers carry **ethyl oleate** in the crop, and contact with foragers slows the maturation of young bees, so a colony full of foragers suppresses its young bees and a colony short of them stops suppressing.

The diagnostic payoff is large. Heavy *Varroa* parasitism during the pupal stage, protein starvation in the first week, sublethal pesticide exposure and *Vairimorpha (Nosema)* infection all accelerate behavioral maturation: the bee forages too young, performs poorly and dies early. A heavily parasitized colony's foraging force can collapse while the frame count still looks respectable, because the bees present are physiologically old. When a colony has adequate bees, adequate stores and no work getting done, ask what happened to those bees as pupae.

1.4 The Glands of the Worker

Hypopharyngeal glands. Paired, filling much of the head, each a duct bearing hundreds of acini. They enlarge over the first week to ten days, peaking in nurses around days six to twelve, secreting the protein-rich fraction of brood food including the major royal jelly proteins. At the transition to foraging the acini shrink and the secretion shifts to the carbohydrate-processing enzymes of honey ripening - invertase above all, plus glucose oxidase. Premature atrophy follows pollen deprivation, and also *Vairimorpha (Nosema)* infection, heavy *Varroa* parasitism and several pesticide exposures. This is why a

colony short of pollen cannot rear brood however much honey it holds: brood food needs dietary protein and honey has almost none. The regression is reversible, which is what lets reverted foragers nurse again.

Mandibular glands. In nurses they supply the lipid fraction of brood food, notably 10-hydroxy-2-decenoic acid, the standard marker of royal jelly authenticity. In older workers and guards they make 2-heptanone, once classed as an alarm pheromone but now understood mainly as an anaesthetic delivered in a bite against small intruders (Chapter 2). In the queen they make queen mandibular pheromone. One gland, three products, by caste and age.

Wax glands. Four pairs on the **sternites**, the ventral plates of the abdomen, visible as wax mirrors on segments four through seven. They peak at roughly twelve to eighteen days and then regress, but not permanently; a colony can be pushed to redevelop them when comb is needed, which is why heavy feeding during a dearth still gets comb drawn and why a package of older field bees is slow to start. Wax is expensive: published conversion figures range from about six to eight and a half kilograms of honey per kilogram of wax, the spread reflecting temperature and whether brood is also being reared. Scales weigh about a milligram each, roughly a thousand to the gram. Secretion needs a warm cluster, in the low to mid nineties Fahrenheit, and abundant incoming carbohydrate - hence comb drawn readily during a flow and hardly at all during a dearth. Wax glands develop properly only in bees that got adequate pollen in their first five or six days.

Nasonov gland. On the **dorsal** abdomen, exposed by flexing the tip down to open the membrane between terga six and seven, and fanned into the air. The secretion is a terpenoid blend - geraniol, nerol, both citral isomers, nerolic and geranic acids, farnesol - and the whole blend works far better than any component alone. It marks the nest entrance, assembles and stabilizes swarm clusters, and marks water sources. Workers only. It is used mainly where a resource carries no scent of its own, such as water or an unscented feeder, rather than at flowers that are already scented.

Others. The acid (venom) and alkaline glands feed the venom sac; the Koschevnikov gland near the sting chamber is a principal source of alarm pheromone; **tarsal (Arnhart) glands** on the feet produce footprint pheromone; **labial glands** produce a watery secretion for dissolving sugar crystals and softening wax.

1.5 Vitellogenin, Juvenile Hormone and the Winter Bee

Vitellogenin is a large glycolipoprotein made in the **fat body**, the diffuse tissue lining the abdominal wall that serves as liver and nutrient store. It is secreted into the hemolymph, high in nurse bees and winter bees, low in foragers. It does at least four things, and a candidate should name two: it is a **protein and amino acid reserve** drawn down to make brood food, so a nurse feeding larvae spends her own body protein; it is an **antioxidant** against the oxidative damage of aerobic metabolism, the main mechanistic account of winter bee longevity; it **supports immune function**, binding zinc and sustaining hemocytes; and it **regulates behavioral maturation** through mutual repression with juvenile hormone.

The **winter bee**, or diutinus bee, is the same genotype as a summer worker in a different physiological state: enlarged fat body, high vitellogenin, low juvenile hormone, lifespan of four to six months against

four to six weeks. She is not a separate egg type, not a retained drone, and not merely a summer bee slowed by cold - a winter bee kept warm still outlives a summer bee.

Two conditions produce her. A **decline in open brood** removes the drain on vitellogenin, so nurses accumulate reserves instead of spending them, and **good late-season protein intake** supplies the raw material. In the southeastern US both are easy to miss: a mild autumn with goldenrod and aster encourages colonies to brood hard into November, producing physiologically summer-type bees at precisely the wrong moment, and where autumn pollen fails instead the raw material is absent and the result is the same. Either way the colony looks strong in October and is a handful of bees around a dead queen in February. No January inspection fixes what was decided in September.

This is the bridge to *Varroa*. What the mite eats depends on the host's stage. On adult bees it feeds mainly on **fat body tissue** - the correction to the old hemolymph-only view made by Ramsey and colleagues in 2019. On pupae in the sealed cell, a 2024 study by Han and colleagues found that the reproducing mite family feeds mainly on **hemolymph**. Either way the drain falls on the vitellogenin system: hemolymph carries the nutrients from which the pupa builds its fat body, during the very window when she is building it, and in the adult the fat body itself is eaten. So a parasitized pupa emerges with a depleted fat body, low vitellogenin, weakened immunity and a shortened life whether or not her wings are deformed. That is why the late-summer mite threshold is the decisive management point of the year: mites present in August damage the bees that must live until March. Stated positively, a broodless or nearly broodless period lets nurses accumulate vitellogenin, so induced broodless intervals are valuable physiologically as well as for mite control.

1.6 The Alimentary Canal and the Logic of the Proventriculus

The gut is built around a problem: the bee must carry a liquid load without digesting it.

Liquids are drawn up by the **proboscis**, a temporary assembly of glossa, galeae and labial palps that interlock into a tube and fold away when not in use; tongue length runs about 6.3 to 6.7 mm in Italian-derived stock, which governs which flowers, such as deep-tubed red clover, are reachable. Solids are handled by the **mandibles**, spoon-shaped and unnotched in the honey bee. From the pharynx the esophagus runs through the thorax to the **crop**, or honey stomach: a thin, cuticle-lined sac that distends roughly tenfold and holds on the order of 40 to 60 microliters full. Nothing is absorbed there. Nectar sits mixed with the enzymes added at the flower and is regurgitated at the hive.

Between crop and midgut sits the **proventriculus**, and it is why the arrangement works. It is a muscular valve with four spined triangular lips whose function is to **filter pollen grains and other particles out of the crop contents and pass them into the midgut**, leaving relatively particle-free nectar behind. It works actively and continuously and can concentrate pollen substantially. Three consequences follow. A forager can carry a full crop load without digesting it, feeding herself from that same load at whatever rate she needs. Pollen picked up incidentally in nectar is largely removed before the nectar reaches a house bee, which is one reason honey holds relatively little pollen for the amount of foraging behind it, and why melissopalynology works on a small, non-proportional sample rather than a census. And the same valve is the gate through which *Vairimorpha* spores reach the midgut.

The **ventriculus** or midgut is the true stomach, where pollen is digested and nutrients absorbed. Its epithelium secretes the **peritrophic membrane**, a sheath enclosing the food bolus that protects the epithelium from abrasion by pollen grains and forms the barrier a germinating *Vairimorpha* spore must cross when it fires its polar filament into an epithelial cell. Malpighian tubules empty nitrogenous waste into the gut at the midgut-hindgut junction.

The **hindgut** is ileum plus **rectum**. Six longitudinal **rectal pads** resorb water, salts and residual nutrients from the fecal mass. Their significance is retention: because water is reclaimed, feces can be held and compacted, letting a bee retain waste for weeks when flight is impossible, and a wintering bee may carry a substantial fraction of her body weight as retained feces. Retention capacity is finite, which is the origin of **dysentery**: when the indigestible fraction is high, the moisture load excessive, or confinement prolonged, bees void inside the hive. Dysentery is a sign, not a disease, and it is frequently blamed on nosema wrongly. In much of the southeastern US prolonged confinement is uncommon, because mild spells permit frequent cleansing flights, so dysentery there usually points to fermented syrup, excess hive moisture or unsuitable stores such as honeydew honey.

The principal sugar in hemolymph is **trehalose**, a non-reducing disaccharide of two glucose units made in the fat body. Non-reducing is the point: it can be carried at high concentration without glycating hemolymph proteins, giving a circulating energy pool far larger than a vertebrate could tolerate as free glucose, and trehalase splits it at the flight muscle at the point of use. Trehalose depletion is the physiological definition of flight-fuel exhaustion, which is why a forager caught by a sudden cold snap or confined without food collapses abruptly rather than fading - there is no large lipid reserve, only a modest fat-body glycogen buffer. The same fact explains how fast a starving colony deteriorates once stores run out. There is no meaningful reserve outside the stored honey.

1.7 Collecting and Converting: Corbicula, Beebread and the Honey Enzymes

Pollen on the body is combed off and worked backward, from the middle legs to the pollen brushes on the inner face of the hind basitarsi; the rastellum, a comb of stiff spines on the end of the opposite hind tibia, rakes it from those brushes. The **pollen press**, the joint between hind tibia and basitarsus, compresses the pollen and **extrudes it upward onto the corbicula** - the concave outer surface of the hind tibia, fringed with long incurved hairs and bearing one stiff hair through the center of the load. The load is moistened with regurgitated nectar and glandular secretion so it coheres, and the central hair anchors it. Two practical points follow. Corbicular pollen is moist and sugary, so a trapped pollen crop is perishable and must be dried or frozen within hours rather than left in the trap drawer overnight in July. And very dry, non-sticky pollens, including the pines that dust the coastal plain yellow each spring, pack poorly and are collected inefficiently, which is why a spectacular pine bloom contributes little to nutrition.

Beebread is pollen that workers have packed into cells and mixed with honey and glandular secretions, tamped down and usually sealed with honey. The additions drop the pH to around 4 and, with the honey seal excluding air, suppress spoilage organisms. Fresh corbicular pollen moulds or ferments within hours to days in warm humid weather; beebread keeps for months. It is the colony's

stored protein reserve. The older account described beebread as a lactic fermentation like silage; Anderson and colleagues found far less microbial activity than that model predicts and argue it is better understood as a **preserved** product, protected by acidity, low water activity and the honey coating. Know both, and know the preservation model has the better recent evidence.

The reason this matters is assessment. **Honey stores tell you nothing about protein reserve.** A colony with sixty pounds of capped honey and no beebread cannot rear brood. Assess frames of stored beebread, not incoming pollen loads - loads at the entrance tell you what is available today, not what the colony can draw on when forage fails, which is exactly the question in a dearth.

The related diagnosis is a colony that stops rearing brood in midsummer despite warm weather and a laying queen. Two nutritional explanations dominate and they call for opposite responses. A **pollen dearth** means no protein for brood food; a **pollen- and honey-bound brood nest** means beebread and nectar have filled the cells she would lay in. The separating observation is stored beebread and available laying space: a dearth shows little or no beebread with empty polished cells standing ready, a bound nest shows combs packed wall to wall and nowhere to lay. Feed protein for the first; give drawn comb or foundation and move filled frames out of the brood area for the second. The southeastern summer dearth makes the first common, while a heavy late-spring flow into a colony short of super space produces the second.

Two enzymes from the hypopharyngeal glands make honey. Invertase, also called sucrase or alpha-glucosidase, hydrolyzes sucrose into glucose and fructose, which is what turns a sucrose-dominated nectar into honey. Glucose oxidase acts on glucose to produce gluconic acid, the principal acid of honey and the main reason its pH sits near 3.2 to 4.5, and hydrogen peroxide, which supplies much of honey's antibacterial activity. That reaction needs water, and ripe honey has too little free water for it to run - which explains a result that surprises people: diluted honey shows far greater peroxide activity than neat honey. Catalase carried in on pollen destroys peroxide, so high-pollen honeys show lower activity. Both enzymes are heat-labile, and their activity, with diastase number and hydroxymethylfurfural, indexes heat abuse and age. Ripening itself is physical: nectar arriving at 20 to 70 percent water is spread in droplets, worked repeatedly on the mouthparts, and fanned until moisture falls below about 18.6 percent, at which point the cell is capped.

1.8 Circulation and Respiration

The honey bee has an **open circulatory system**. Hemolymph is not confined to vessels; it fills the body cavity and bathes the organs. A **dorsal vessel** runs the length of the body - a segmented heart in the abdomen with paired ostia admitting hemolymph, continuing forward as the aorta and discharging into the head - and hemolymph percolates back through the body cavity, directed by dorsal and ventral diaphragms. It carries nutrients, trehalose, vitellogenin, hormones and hemocytes, and it **carries no respiratory pigment**: no hemoglobin, no hemocyanin. It is clear to amber, not red, and it delivers no oxygen.

Oxygen is delivered by the **tracheal system**: air-filled tubes opening at the **spiracles**, ten pairs in the adult worker, three thoracic and seven abdominal, each guarded by hairs and a closing mechanism.

Tracheae branch to fine tracheoles terminating directly on the tissues, effectively on individual flight-muscle fibers, and large **air sacs** act as bellows ventilated by rhythmic abdominal pumping.

Three things follow. **Gas delivery is local, so damage is local**: tracheal mite infestation degrades oxygen supply to the muscles served by the affected tracheae and is not a circulating deficit analogous to anemia. **Carbon dioxide narcosis is fast and reversible**, because CO2 also reaches the tissues directly through the tracheae rather than via a circulation; a bee goes down in seconds and recovers in minutes, which is what makes it usable for handling queens during instrumental insemination, though CO2 is not inert - it stimulates ovary development and hastens laying onset in inseminated queens, and repeated exposure shortens life. And **fumigants act through the tracheae**, which is why ventilation, ambient temperature and hive volume are treatment variables for formic and oxalic acid vapor.

The pair of diagnostic importance is the **first thoracic pair**, the route by which *Acarapis woodi*, the tracheal mite, enters the body. A gravid female leaves an older bee, transfers by contact, and must find and enter the prothoracic spiracle of a bee **less than about four days old**; in older bees the guard hairs have hardened and behavioral defenses work, and invasion increasingly fails, becoming rare after about nine days. Inside the prothoracic trachea she pierces the tracheal wall to feed on hemolymph and lays five to seven eggs over three or four days, with development taking about eleven to twelve days for males and fourteen to fifteen for females. The narrow window explains the rest: transmission depends on close contact with very young bees, so colony age structure governs spread and continuous brood rearing continuously supplies susceptible hosts. It also explains why diagnosis requires **dissection and microscopic examination of the prothoracic trachea**, or a molecular test. Two non-pathogenic relatives, *Acarapis externus* and *Acarapis dorsalis*, live on the outside of bees and closely resemble *A. woodi*, so finding an *Acarapis* mite externally proves nothing.

1.9 The Sensory World of the Bee

A worker's compound eye carries roughly four to seven thousand ommatidia; a drone's carries more and shows wide variation across studies, on the order of seven to eleven thousand, with a greatly enlarged dorsal region for spotting a queen as a dark object against bright sky. Acuity is poor by our standards but temporal resolution is excellent: flicker fusion frequency is around 200 Hz against roughly 50 to 60 for a human, so bees resolve fast motion we see as a blur - one reason a quick movement near the entrance provokes a response a slow one does not.

Bee color vision is **trichromatic but shifted into the ultraviolet**. The three receptor classes peak in the **ultraviolet** near 344 nm, the **blue** near 436 nm and the **green** near 544 nm. There is no red receptor, and bees are effectively **red-blind**: a pure red surface reads as dark unless it also reflects ultraviolet. Hence the ultraviolet nectar guides on many bee flowers, invisible to us and conspicuous to a bee; hence deep red flowers such as trumpet creeper and cardinal flower being largely hummingbird plants; hence most white flowers, which absorb ultraviolet, reading to a bee as blue-green rather than white; and hence a red-painted hive front being a poor landmark while blue, yellow and white markings reduce drifting effectively.

Bees also detect the **polarization pattern of skylight**. Specialized ommatidia in the dorsal rim area read the e-vector pattern and infer the sun's azimuth even when the sun is hidden, so a patch of blue sky is enough. That is why the waggle dance, which encodes direction relative to the sun's azimuth, remains usable under broken overcast, and it works alongside a time-compensated sun compass that corrects for the sun's movement, including during a long stay in the dark hive. Three **ocelli** on top of the head form no image; they measure light intensity, govern the timing of flight onset and cessation, and help stabilize flight against the horizon.

Antennae are the main olfactory organs: twelve segments in workers and queens, thirteen in drones, being scape, pedicel and flagellum - the extra flagellar segment is a quick field method for sexing a bee. Antennal surfaces carry **plate organs** numbering in the thousands on a worker and up to roughly thirty thousand on a drone, the anatomical basis for detecting a queen's pheromone plume across many meters at a congregation area. In the pedicel lies **Johnston's organ**, which detects air-particle movement; it lets a follower bee in the dark read the near-field air currents from a waggle dancer's wing vibrations and serves as an airspeed sensor. Subgenual organs in the legs detect substrate vibration, the sensory basis of the vibration and stop signals. Individual bees differ measurably in **sucrose response threshold**, which predicts behavior - low-threshold bees accept dilute nectar and start foraging earlier - and the variation is partly heritable and differs among patrilines.

1.10 Thermoregulation

The brood nest is held at roughly **34 to 35 degrees C, about 93 to 96 degrees F**, with an actively rearing core typically between 34.5 and 35.5. The narrowness of the band is what makes it examinable. Brood reared a degree or two low yields adults with impaired learning and memory, shortened life and greater susceptibility to pesticides and pathogens; too warm produces similar deficits, and extremes produce wing deformities mistakable for deformed wing virus. Nothing about the adult bee repairs a pupal thermal insult.

Warming is done by workers contracting the flight muscles without moving the wings - decoupling wings from muscle and shivering isometrically - which can drive thoracic temperature to roughly 40 to 43 degrees C. Heat is transferred by pressing the thorax flat against the capping of a pupal cell, and, as Kleinhenz, Bujok, Fuchs and Tautz showed in 2003, by **entering an empty cell inside the brood area** and warming the capped cells around it (up to six neighbors directly, with heat detectable up to three cells away) through the shared walls. That has a practical corollary: scattered empty cells within an otherwise solid brood pattern are a normal, functional feature of a working brood nest, not automatic evidence of disease or a failing queen.

Cooling uses evaporation. Water foragers - a distinct specialization, recruited when house bees are slow to relieve them - bring water in; house bees spread it as thin films on cell rims and cappings and hold droplets on the extended tongue to increase surface area. Workers fan in coordinated chains, often oriented at the entrance to drive directed airflow, and at high heat loads surplus bees leave the cavity and beard on the front. A strong colony in southeastern summer heat may collect a liter (about a quart) or more of water a day, which is why an apiary sited without clean water pushes its bees onto swimming pools and livestock troughs.

The **winter cluster** is a different regime. Clustering begins around 14 degrees C ambient, roughly 57 degrees F, and a dense outer mantle insulates a looser core. The mantle is held no lower than about 8 to 10 degrees C, which is not incidental: below roughly 8 degrees C a bee enters chill coma and loses her grip. A broodless winter core is held well below brood-nest temperature, somewhere between about 18 and 32 degrees C depending on conditions - the colony does not hold brood-nest temperature all winter, and that is a common examination trap. Once brood rearing resumes the core is raised to 34 to 35 degrees C and held there, and consumption rises steeply. The cluster moves as a unit and **cannot cross a frame of cold empty comb**; colonies starve every winter with honey two frames away, which governs how stores should be arranged and why splitting a brood nest across boxes in cold weather is a serious error.

The southeastern corollary is counterintuitive: mild winters can cost more stores than cold ones, because a colony that never goes broodless never stops holding 34 to 35 degrees C over brood and never stops feeding larvae. A warm January is a reason to heft hives, not to relax. At the upper end, adult bees begin dying around 48 to 50 degrees C and brood dies below that - the basis of heat treatment for wax moth and small hive beetle in stored equipment, and the reason a closed vehicle in summer sun kills a load of colonies in under an hour.

1.11 Pheromones, Cohesion and the Suppression of Worker Reproduction

Pheromones have **releaser** effects, producing an immediate behavioral response, and **primer** effects, changing physiology over time. Most of the important ones do both.

Queen mandibular pheromone (QMP) is a blend from the queen's mandibular glands dominated by 9-oxo-2-decenoic acid (9-ODA), with 9-hydroxy-2-decenoic acid in both enantiomers, methyl p-hydroxybenzoate and 4-hydroxy-3-methoxyphenylethanol; the full queen signal is broader, with contributions from tergal, tarsal and Koschevnikov glands.

Its mode of distribution is the key to everything. QMP is not broadcast. Retinue workers lick and antennate the queen, acquire the compounds, and pass them on by contact and food sharing, so the signal propagates as a diluting chain and **the dose an individual bee receives falls as the colony grows, as the brood nest congests, and as worker movement through the nest is impeded**. That is the biological bridge between congestion and swarming: below a threshold dose, inhibition lifts and workers provision queen cups. It follows that **relieving crowding is swarm control and cutting cells is not** - adding space, reversing, removing frames of capped brood or splitting all restore distribution, while cutting cells removes the symptom, leaves the cause, and commits you to finding every cell on a seven-day cycle indefinitely. The same mechanism explains supersedure in an aging, failing or injured queen whose output declines. QMP also holds a swarm cluster together, inhibits worker ovary development, stimulates foraging and comb building, and, as 9-ODA, serves as the long-range sex attractant drawing drones to a queen at a congregation area. **Footprint or tarsal pheromone**, deposited from the Arnhart glands as she walks, adds a spatially local inhibition of queen cup construction on the comb faces she covers, which is why a colony whose queen cannot easily traverse the whole brood nest starts cups at the margins first.

Larvae produce their own signal, a blend of cuticular fatty acid esters plus volatile E-beta-ocimene from young larvae. Brood pheromone stimulates pollen foraging, primes hypopharyngeal gland development in nurses, triggers capping at the right moment, and **inhibits worker ovary development**. Workers do possess ovarioles, typically two to twelve per ovary, and can activate their ovaries; in a queenright colony this is suppressed by the **combined** action of queen pheromone and open brood pheromone, and it takes both. That is why laying workers appear only after prolonged queenlessness with no young brood, and why giving a laying-worker colony repeated frames of open brood can suppress the condition. The other half of suppression is behavioral: **worker policing**, in which nestmates recognize and remove worker-laid eggs, apparently by the absence of a queen-derived marking. That is why a beekeeper rarely sees worker-laid brood in a colony queenless only a short time - the eggs are laid and eaten. Once established the picture is unmistakable: multiple eggs per cell, eggs on cell walls rather than centered, drone brood in worker cells under domed bullet cappings, and rejection of introduced queens.

The alarm pheromone that matters in the apiary is associated with the **sting apparatus**, released from the Koschevnikov gland and the sting chamber when a bee stings or merely extrudes her sting in alarm. Its best-known component is **isopentyl acetate** (isoamyl acetate), source of the banana odor, within a blend of more than forty identified compounds, and its function is to **mark the target and recruit further defenders to that specific spot**. **2-heptanone** from the mandibular glands of older workers and guards was long counted as a second alarm substance; it is now understood mainly as an anaesthetic delivered in a bite (Chapter 2). The consequences are immediate. A sting delivered into a glove, veil or boot marks that spot and further defenders aim there, so smoke it or remove the item. **Crushing bees releases the same signal**, so careful handling and light smoke reduce escalation for chemical reasons, not aesthetic ones. The banana smell is a quantitative field cue: when you can smell it, you have exceeded the colony's tolerance. And a colony disturbed without any sting being delivered can still escalate, because the pheromone is released on extrusion as well as on penetration.

1.12 Defense: Smoke, the Sting Apparatus and Venom

Smoke calms a colony chiefly by **masking and disrupting the perception of alarm pheromone**, reducing antennal sensitivity so the recruitment cascade breaks before it builds (Visscher et al. 1995). The traditional explanation, that bees gorge on honey in anticipation of fleeing a fire, which occupies them and makes stinging harder, is plausible and widely taught but has not been demonstrated experimentally.

Technique follows from mechanism. **Cool white smoke, lightly applied, then given thirty to sixty seconds to act** beats volume every time - a few puffs at the entrance, a few under the inner cover, then wait. Hot or heavy smoke drives bees off the combs and provokes rather than calms. Fuel must be untreated natural material such as pine straw, dry leaves, untreated burlap or wood shavings, never painted or pressure-treated wood and never synthetic fabric, and heavy smoking around open supers taints honey. In the pine landscapes of the southeastern US a smoldering smoker is a serious wildfire hazard: extinguish deliberately, plug the spout, and transport it in a closed metal container.

The sting is a modified ovipositor, which is why only females have one - drones have no sting at all. Two **lancets** slide alternately along a grooved stylus, driven by muscles in the sting bulb and coordinated by

the terminal abdominal ganglion, and each lancet bears about **ten backward-facing barbs**. Those barbs anchor in elastic vertebrate skin, so when the worker pulls away the whole apparatus - lancets, stylus, venom sac, muscles, glands and terminal ganglion - tears free. This **autotomy** kills the bee, from the abdominal rupture rather than from the loss of the sting itself. The detached apparatus is autonomous: it keeps driving the lancets deeper, keeps pumping venom, and keeps releasing alarm pheromone marking the site. A sting delivered into another insect's cuticle usually withdraws cleanly. A queen's sting is smoother, curved and largely unbarbed; she can sting repeatedly and survive, and uses it almost exclusively on rival queens. The instruction has changed from the older teaching: **remove the sting immediately, by whatever method is fastest**. The advice to scrape rather than pinch, on the theory that pinching squeezes the sac, is not supported - dose is a function of time, and the seconds lost finding a hive tool cost more venom than any squeeze.

A worker's venom sac holds on the order of 150 micrograms dry weight, of which a fraction is typically delivered. **Melittin** dominates at roughly half the dry weight, with published figures ranging from about 40 to 60 percent; it is a small amphipathic peptide that inserts into and disrupts cell membranes, and it causes most of the **immediate pain** and the local tissue effect. **Phospholipase A2** accounts for about ten to twelve percent; it is an enzyme, acts synergistically with melittin on membranes, and is the **principal allergen** in IgE-mediated sensitization. That contrast is the teaching point: the component responsible for most of the pain is not the one responsible for most of the allergy. Among minor components, **hyaluronidase** at a few percent degrades hyaluronic acid in connective tissue and acts as a spreading factor; **apamin** is a small neurotoxin; **MCD peptide** degranulates mast cells, releasing histamine. Formic acid is not a significant constituent of honey bee venom, despite persistent folklore.

This supports the explanation beekeepers are most often asked for. A **large local reaction** - swelling that may involve a whole limb, developing over twenty-four to forty-eight hours and resolving over several days - is a delayed, mostly IgE-mediated allergic response confined to the sting region, not anaphylaxis, though it does show the person is sensitized. A **systemic reaction** involves organ systems distant from the sting: generalized hives, swelling of the face or airway, wheezing, faintness, vomiting, a drop in blood pressure. That is an emergency requiring epinephrine and transport. Tolerance is also acquired and maintained by regular exposure, so a beekeeper who takes a season off may react more strongly on resuming.

1.13 Queen and Drone Reproductive Physiology

The queen's abdomen is largely filled by two ovaries; eggs pass down the lateral oviducts into the median oviduct. Beside it sits the **spermatheca**, a sac about a millimeter across with its own dense tracheal supply and a gland maintaining the storage environment. It holds on the order of five to seven million spermatozoa, acquired on her mating flights and mixed from all the drones she mated with. Fertilization is under her control at laying: she measures cell width with forelegs and antennae, releasing sperm as the egg passes the spermathecal duct into a worker-width cell and withholding it for a drone-width cell.

The decisive fact is that **the spermatheca is filled once and never replenished**. There are no further mating flights after the first week or two of adult life and no recovery in a later season. A queen that

mated poorly - few drones, a cold or wet mating window, a thin local drone population - starts with less and runs out sooner, becoming a drone layer: scattered drone brood in worker cells under domed cappings, a declining worker population, and a colony on the way out unless requeened. Stored sperm can also be destroyed after the fact. **Temperature extremes in shipping or holding**, outside a safe zone of roughly 15 to 38 degrees C (59 to 100 degrees F) and most severely below about 5 or above about 40 degrees C, kill stored spermatozoa with **no visible sign in the queen** - she looks sound, moves well and is accepted normally. Pettis and colleagues documented reduced sperm viability in a substantial proportion of commercially shipped queens, which is a leading suspected cause of early supersedure and of partial drone-laying in queens that arrived apparently healthy. It is preventable at the beekeeper's end: never leave queen cages on a dashboard, in a closed vehicle, in direct sun, or in a refrigerator. At spring peak a good queen lays 1,500 to 2,000 eggs a day, which at roughly 0.13 mg per egg exceeds her own body weight daily and is why she must be fed continuously by her retinue.

A drone develops from an unfertilized egg over twenty-four days and **emerges sexually immature**: spermatogenesis is completed during the pupal stage, and over the first days of adult life the sperm migrate from the testes to the seminal vesicles, after which the testes degenerate. He needs roughly **twelve to sixteen days after emergence** to become capable of mating, with flights beginning around day twelve. Mature drones fly on warm afternoons, characteristically between about 2:00 and 5:00 pm, needing roughly 20 degrees C (68 degrees F) and calm conditions. They fly to **drone congregation areas**: persistent aerial sites 10 to 40 meters up and 30 to 200 meters across, typically one to three kilometers from the apiaries that supply them, used year after year by successive generations that cannot have learned them from one another. Drones from a great many colonies assemble at one DCA, so a virgin flying there samples broadly and is unlikely to meet her own brothers. Mating occurs in flight: the drone everts the endophallus, mates, and it is torn from his body with an audible pop; he falls and dies, and the mating sign is removed by the next drone. A queen usually makes one to three mating flights (occasionally up to five) over two to four days and mates with **twelve to twenty or more** drones. The management consequence is direct: **drone mother colonies must be established well ahead of any mating window**, since twenty-four days from egg plus twelve to sixteen more to maturity means nearly six weeks from laying to a useful drone.

Because the queen mates with many drones and stores their sperm mixed together, **the workers in a colony are not all full sisters.** They comprise many **patrilines**. Workers sharing a father are **full sisters related by three quarters**, because the haploid father passes his entire genome to every daughter, plus half the mother's; workers with different fathers are **half sisters related by one quarter**. The resulting diversity produces measurable colony-level advantages, shown by Mattila and Seeley and by Jones and colleagues among others: more precise thermoregulation, greater disease resistance, more consistent foraging, more comb built, more brood reared and better overwintering. The thermoregulation mechanism generalizes. Patrilines differ in the temperature threshold at which individual bees begin fanning or shivering; in a genetically uniform colony all bees cross that threshold together, producing an all-or-nothing response that overshoots and oscillates, while in a diverse colony patrilines respond in sequence, giving a **graded** response that holds the brood nest in a narrower band. The same logic underlies the diversity benefit in foraging and in defense. One corollary closes the loop on stock

selection: because open mating draws on every drone-producing colony and every feral colony for kilometers around, **the daughters of a purchased breeder queen do not reproduce her traits reliably.**

1.14 Numbers to Know Cold

Figure	Value	Why it is that value
Queen development, egg to emergence	16 days	Rich continuous royal jelly accelerates growth; capped about day 8
Worker development, egg to emergence	21 days	Capped about day 9; capped period about 12 days
Drone development, egg to emergence	24 days	Capped about day 10; capped period 14-15 days, the longest
Queen cell capping	about day 8	Prime swarm issues at or shortly after capping; basis of the 7-day round
Larval instars	5	Fifth spins, voids gut, becomes prepupa
Nurse visits to a worker larva	about 1,300 per day (over 10,000 in total)	The true cost of brood rearing in nurse labor
Brood nest temperature	34-35 degrees C (93-96 degrees F)	Optimum for pupal development; 1-2 degrees low gives adults with impaired learning and short life
Winter cluster mantle	not below about 8-10 degrees C	Below about 8 degrees C a bee enters chill coma and loses her grip
Broodless winter core	roughly 18-32 degrees C, well below brood-nest level	Brood-nest temperature is not held all winter, only once rearing resumes
Clustering begins	about 14 degrees C (57 degrees F)	Below this, individual thermoregulation fails and bees aggregate
Lethal upper limit, adults	about 48-50 degrees C	Basis of heat treatment for stored comb pests; brood dies below this
Worker lifespan, summer	4-6 weeks	Foraging phase 1-2 weeks; wings and flight muscle wear out
Worker lifespan, winter bee	4-6 months	High vitellogenin, enlarged fat body, low juvenile hormone, no brood-feeding drain
Hypopharyngeal gland peak	days 6-12	Nurse phase; regresses at the foraging transition, secretion shifts to invertase
Wax gland peak	days 12-18, sternites 4-7	Four pairs on the ventral abdomen; reversible, so older bees can be induced to build
Honey consumed per unit of wax	roughly 6 to 8.5 : 1 by weight	Energetically costly; needs a warm cluster and abundant carbohydrate

Figure	Value	Why it is that value
Wax scale mass	about 1 mg, roughly 1,000 per gram	A drawn deep frame is tens of thousands of scales
Spiracles, adult worker	10 pairs (3 thoracic, 7 abdominal)	The first thoracic pair is the entry route for *Acarapis woodi*
Tracheal mite invasion window	bees under about 4 days old	Spiracle guard hairs unhardened and defenses weak in newly emerged bees
Photoreceptor peaks	about 344 nm UV, 436 nm blue, 544 nm green	Trichromatic but shifted into UV; effectively red-blind
Flicker fusion frequency	about 200 Hz	Roughly four times the human figure; bees resolve rapid motion
Ommatidia per compound eye	worker about 4,000-7,000; drone about 7,000-11,000	Drone's enlarged dorsal eye region detects a queen against the sky
Antennal segments	12 in worker and queen, 13 in drone	Quick field method for sexing a bee
Queen ovarioles	about 100-180 per ovary (median about 320 total)	Worker keeps only a few per ovary (typically 2-12) after programmed cell death in larval life
Sperm stored in the spermatheca	about 5-7 million	Acquired on mating flights only; never replenished
Drones a queen mates with	about 12-20 or more, over 1-5 flights	Full sisters related by 3/4, half sisters by 1/4
Drone sexual maturity	about 12-16 days after emergence	Plus 24 days from egg: nearly six weeks from laying to a useful drone
Drone flight conditions	warm afternoons, about 2:00-5:00 pm, above about 20 degrees C	DCAs 10-40 m up, typically 1-3 km from the apiary
Peak queen laying rate	1,500-2,000 eggs per day	More than her own body weight daily; requires continuous feeding
Crop capacity	on the order of 40-60 microliters full	Distends about tenfold; nothing is absorbed there
Honey moisture at capping	below about 18.6 percent	Water activity too low for osmophilic yeasts to ferment it
Honey pH	about 3.2-4.5	Gluconic acid from glucose oxidase is the principal acid
Melittin in venom	roughly 40-60 percent of dry weight	Membrane-disrupting peptide; source of most immediate pain
Phospholipase A2 in venom	about 10-12 percent of dry weight	The principal allergen in IgE-mediated sensitization

Figure	Value	Why it is that value
Venom per sting	about 150 micrograms dry weight in the sac	Delivered dose depends on how long the apparatus stays in
Barbs per sting lancet	about 10	Anchor in elastic skin, causing autotomy; the detached apparatus keeps pumping

1.15 Common Misconceptions

Misconception: A spotty brood pattern with no disease signs means the queen is failing. **Correction:** Inbreeding is a common cause, and requeening from the same line will not fix it. Fertilized eggs homozygous at the *csd* locus develop as diploid drones and are cannibalized within hours of hatching, leaving cells that look as though nothing was laid in them. The diagnostic picture is scattered brood with normal eggs, no odor, no ropiness and negligible mite counts. The remedy is unrelated genetics.

Misconception: Queens develop from eggs that differ from the ones producing workers. **Correction:** They come from identical fertilized eggs; quantity, composition and duration of larval feeding direct the two pathways. This is why grafting age is the largest controllable determinant of queen quality, and why a queen raised from a larva older than about three days has fewer ovarioles, a smaller spermatheca and a lower emergence weight.

Misconception: Bees begin foraging at three weeks old because that is how they are built. **Correction:** Age of first foraging is a flexible default set by hormonal state interacting with colony demand. Strip the foragers and young bees forage at seven days; strip the nurses and foragers revert with redeveloped hypopharyngeal glands. Mite damage, poor nutrition and pesticide exposure all accelerate the transition, producing short-lived, poorly performing adults.

Misconception: Winter bees are ordinary bees that live longer because cold slows them down. **Correction:** They are physiologically distinct - enlarged fat bodies, high vitellogenin, low juvenile hormone - and their longevity is a property of that state, not of ambient temperature. They are produced by a decline in open brood together with good late-season pollen, which is why a colony brooding hard through a mild southeastern autumn enters winter with summer-type bees and dwindles.

Misconception: A colony with plenty of capped honey has plenty of food. **Correction:** Honey is carbohydrate with almost no usable protein. Brood rearing requires protein for hypopharyngeal gland secretion, and the protein reserve is stored beebread. A colony with sixty pounds of honey and no beebread will stop rearing brood. Assess frames of beebread, not honey weight or incoming pollen loads.

Misconception: Nectar starts being digested in the crop on the flight home. **Correction:** The crop is a cuticle-lined transport vessel where nothing is absorbed. The proventriculus, the valve between crop and midgut, filters pollen and particles out of the crop contents and passes them into the midgut, which is exactly what keeps the load transportable. The enzymes were added at the flower and at unloading.

Misconception: Hemolymph carries oxygen, so impaired circulation starves the tissues. **Correction:** Hemolymph carries no respiratory pigment at all. Oxygen reaches tissues directly through tracheae and

tracheoles from ten pairs of spiracles, with air sacs ventilated by abdominal pumping. Delivery is local: tracheal mite damage is a local blockage, not a circulating deficit, and carbon dioxide narcosis is fast and reversible because CO2 reaches the tissues the same direct way.

Misconception: Finding *Acarapis* mites on the outside of bees confirms tracheal mites. **Correction:** Two non-pathogenic external species, *Acarapis externus* and *Acarapis dorsalis*, live on honey bees and closely resemble *A. woodi*. Diagnosis requires dissection and microscopic examination of the prothoracic trachea, or a molecular test. External mites prove nothing.

Misconception: Bees see red well, which is why red flowers attract them. **Correction:** The receptor set is ultraviolet, blue and green, with no red receptor, so bees are effectively red-blind and a pure red surface reads as dark. Deep red flowers such as trumpet creeper and cardinal flower are hummingbird plants. Bees also read the polarization pattern of skylight, letting them navigate from a patch of blue sky when the sun is hidden.

Misconception: Empty cells scattered through the brood pattern always mean disease or a failing queen. **Correction:** Heater bees enter empty cells inside the brood area and warm the capped brood cells around them through the shared walls, so a functioning brood nest normally contains such cells. Judge the pattern on its other features: uniform capping, eggs and larvae in proportion, no odor, no sunken or perforated cappings.

Misconception: A queen laying poorly can mate again, or will recover next spring. **Correction:** The spermatheca is filled once, on flights in the first week or two of adult life, and is never replenished. A poorly mated queen, or one whose stored sperm was killed by heat or cold in shipping, becomes a drone layer. Shipping damage leaves no visible sign, which is why an apparently sound queen can supersede early or lay patchy drone brood weeks later.

Misconception: Cutting queen cells is swarm control. **Correction:** Queen mandibular pheromone is distributed by contact and food sharing, so the per-bee dose falls as the colony grows and congests. Cells are the symptom of that falling dose. Cutting them leaves the cause untouched, commits you to finding every cell on a seven-day cycle indefinitely, and fails the first time you miss one. Relieving congestion addresses the signal deficit itself.

Misconception: Smoke works because bees think the hive is burning and are too busy to notice you. **Correction:** The best-supported mechanism is that smoke masks and disrupts the perception of alarm pheromone, breaking the defender-recruitment cascade; the idea that it also makes bees engorge, which occupies them and leaves them less able to flex the abdomen far enough to sting, is traditional but untested. Cool light smoke given half a minute works; hot or heavy smoke drives bees off the combs and provokes.

Misconception: Whether you scrape or pinch a sting out matters more than how fast you do it. **Correction:** The detached apparatus is autonomous, carrying venom sac, driving muscles and terminal ganglion, and continues to drive the lancets deeper and pump venom. Dose is a function of time, so the delay in finding the right tool costs more venom than any squeeze. Remove it at once, by whatever means is at hand.

Misconception: A swollen arm after a sting means you are becoming allergic. **Correction:** That is usually a large local reaction, a delayed, mostly IgE-mediated allergic response confined to the sting region, peaking at 24 to 48 hours and clearing in several days, with hyaluronidase helping the venom spread through connective tissue. It is not anaphylaxis, and the risk of a later systemic reaction is low (on the order of 5 to 10 percent), but it does mean the person is sensitized, so a beekeeper with repeated large reactions should see an allergist. The principal allergen is phospholipase A2, roughly a tenth of dry weight. Systemic reactions involve organ systems away from the sting - generalized hives, airway swelling, wheezing, faintness - and require epinephrine and emergency care.

1.16 Self-Check Questions

- A colony has a laying queen, normally distributed eggs, a badly scattered brood pattern, no odor, no ropy larvae and a mite count of one per hundred bees. Give the most likely explanation and the management response.
- Explain why a seven-day inspection interval, rather than ten, is standard during swarm season. Give the number your answer depends on.
- Two colonies are equally strong on 1 October; one brooded heavily through a warm autumn, the other went nearly broodless in early September with good fall pollen. Which is likelier to reach March, and why?
- Why does a colony with sixty pounds of capped honey sometimes stop rearing brood in July? Give two nutritional explanations and the observation that separates them.
- Explain mechanistically why *Varroa* parasitism during the pupal stage damages overwintering capacity even in bees that emerge with normal wings.
- Distinguish the function of the crop from that of the proventriculus, and state two consequences of the proventriculus's filtering action.
- A beekeeper argues that since bees have an open circulatory system, anything impairing circulation must impair oxygen delivery. Correct him, and use the correction to explain why carbon dioxide can anesthetize a queen.
- Why must a drone mother colony be established nearly six weeks before the mating window? Show the arithmetic.
- Explain the mechanism by which congestion leads to queen cell building, and use it to justify why relieving crowding is swarm control while cutting cells is not.
- State the brood nest temperature range, describe both warming mechanisms, and explain why scattered empty cells in a brood pattern are not automatically a bad sign.
- Explain why the workers in one colony are not all full sisters, give the two coefficients of relatedness, and explain how genetic diversity improves thermoregulation.
- A new beekeeper is stung on the forearm and the whole forearm swells over two days. Explain what is happening in terms of venom composition, and say what would actually indicate a systemic reaction.

- Name the two enzymes central to honey formation, state what each does, and explain why diluted honey shows greater peroxide activity than honey straight from the jar.

- Explain why a winter cluster in the coastal plain may consume more stores than one several hundred miles north, and what that implies for management.

1.17 Self-Check Answers

- The pattern points to inbreeding, not disease or a failing queen. Fertilized eggs homozygous at the *csd* locus develop as diploid drones, which nurses detect and cannibalize within hours of hatching, leaving cells that look as though nothing was laid in them. Absence of odor, ropiness and mites rules out brood disease and mite damage, and normally distributed eggs show the queen is laying. The response is unrelated genetics: requeening from the same line reproduces the problem, because the cause is alleles shared between the queen and the drones she mated with.

- A queen cell is capped about day eight from the egg, and a prime swarm usually issues at or shortly after capping. On a seven-day round no cell can go from egg to capped between visits, so you always see it in time to act. On a ten-day round a cell laid the day after you leave can be capped, with the swarm gone, before you return. The critical number is the day-eight capping, not the day-sixteen emergence, and the round must be kept through the whole swarm season rather than begun when cells are first noticed.

- The colony that went nearly broodless with good fall pollen. Winter bees are produced by declining open brood, which removes the drain on nurse vitellogenin, and good late-season protein, which supplies the raw material. Those bees carry enlarged fat bodies, high vitellogenin and low juvenile hormone and live four to six months. The colony brooding heavily through a warm autumn is still spending vitellogenin on brood food and is producing summer-type bees with four-to-six-week lifespans. It looks strong in October, dwindles through January, and no winter intervention fixes it.

- Either a pollen dearth or a pollen- and honey-bound brood nest. In a dearth the colony lacks protein to run the hypopharyngeal glands and make brood food, and honey supplies almost none. In a bound nest protein and queen are both fine, but beebread and nectar have filled the cells she would lay in. The separating observation is stored beebread and available laying space: a dearth shows little beebread with empty polished cells ready; a bound nest shows combs packed and nowhere to lay. The responses are opposite - feed protein for the first, give drawn comb and move filled frames out for the second.

- *Varroa* feeds mainly on fat body tissue in adult bees and mainly on hemolymph in developing pupae, and both routes drain the vitellogenin system. The fat body synthesizes vitellogenin, and the pupal drain falls in exactly the window when the bee is building it. A parasitized pupa emerges with a depleted fat body, low circulating vitellogenin, weakened immunity and a shortened life, whether or not deformed wing virus produced visible damage. Since vitellogenin is what makes a winter bee live months rather than weeks, mites present in August damage the bees that must survive to March. That is why the late-summer count is the decisive number and a December treatment is too late.

- The crop is a thin, cuticle-lined, highly distensible transport vessel where nothing is absorbed; nectar is held there and regurgitated at the hive. The proventriculus is the muscular valve

between crop and midgut, bearing four spined lips, which filters pollen and particles out of the crop contents and passes them into the midgut. Two consequences: a forager carries a full load without digesting it and can feed herself from that same load at a controlled rate; and pollen picked up incidentally in nectar is largely removed before the nectar reaches a house bee, which is why honey holds relatively little pollen for the foraging behind it.

- Hemolymph contains no respiratory pigment - no hemoglobin, no hemocyanin - and carries no oxygen. Oxygen is delivered directly through the tracheal system: ten pairs of spiracles feeding tracheae that branch to tracheoles terminating on individual muscle fibers, with air sacs ventilated by abdominal pumping. Delivery is therefore local and independent of circulation. The same fact explains carbon dioxide narcosis: CO2 also reaches the tissues directly through the tracheae rather than having to be carried there, so onset takes seconds and recovery minutes, which is what makes it practical for handling queens during instrumental insemination.

- A drone takes twenty-four days from egg to emergence and emerges sexually immature, because spermatogenesis finishes in the pupal stage and the testes have degenerated by emergence. He then needs about twelve to sixteen days to reach mating condition, with flights starting around day twelve. Twenty-four plus twelve to sixteen gives thirty-six to forty days - better than five weeks, and close to six if you want mature drones rather than barely flying ones. An egg laid today produces a useful drone about six weeks out, so queen rearing schedules must be built backward from the date virgins will fly.

- Queen mandibular pheromone is distributed by contact and trophallaxis: retinue workers acquire it from the queen and pass it on in a diluting chain. The dose an individual worker receives therefore falls as the population grows and congestion impedes movement through the nest. Below a threshold dose, inhibition of queen rearing lifts and workers provision cups, so cells are the symptom of a distribution failure. Relieving congestion - space, reversing, removing capped brood, splitting - restores distribution and addresses the cause. Cutting cells leaves the cause in place, commits you to a permanent seven-day cycle, and fails the first time one is missed.

- The brood nest is held at roughly 34 to 35 degrees C, about 93 to 96 degrees F. Workers warm it by contracting flight muscles without moving the wings, raising thoracic temperature to roughly 40 to 43 degrees C, then either pressing the thorax against a capped cell or entering an empty cell within the brood area and warming the capped brood cells surrounding it through the shared walls. That second mechanism is why empty cells scattered through a brood pattern are a normal feature of a working brood nest. Judge the pattern on its other features: uniform cappings, eggs and larvae in proportion, no odor, no sunken or perforated cappings.

- The queen mates with twelve to twenty or more drones on one to five flights and stores their sperm mixed, so her daughters comprise multiple patrilines. Workers sharing a father are full sisters related by three quarters, because the haploid father passes his entire genome to every daughter; workers with different fathers are half sisters related by one quarter. Diversity improves thermoregulation because patrilines differ in the temperature at which individual bees begin fanning or shivering. A uniform colony crosses that threshold all at once and overshoots; a diverse colony responds in sequence, giving a graded response that holds the nest in a narrower band.

- This is a large local reaction. Melittin, roughly half the venom by dry weight, disrupts cell membranes and causes most of the immediate pain; hyaluronidase degrades connective tissue matrix and helps the venom spread beyond the puncture, which is how a whole forearm swells. The swelling over the next day or two is a delayed, mostly IgE-mediated allergic response, not anaphylaxis, typically peaking at twenty-four to forty-eight hours and resolving over several days. The principal allergen is phospholipase A2, about a tenth of dry weight. A systemic reaction involves organ systems away from the sting - generalized hives, facial or airway swelling, wheezing, faintness, a blood pressure drop - and requires epinephrine and emergency care.

- Invertase, also called sucrase or alpha-glucosidase, hydrolyzes sucrose into glucose and fructose, converting nectar's sucrose into the monosaccharide mixture that is honey. Glucose oxidase acts on glucose to produce gluconic acid, the principal acid of honey and the reason its pH sits near 3.2 to 4.5, and hydrogen peroxide, which supplies much of honey's antibacterial activity. Both come from the hypopharyngeal glands. The peroxide reaction requires water, and ripe honey under 18.6 percent moisture has too little free water for it to run. Diluting the honey supplies that water, the reaction resumes, and peroxide activity rises sharply.

- A colony that never goes broodless never stops holding 34 to 35 degrees C over its brood and never stops feeding larvae, both expensive. A colony farther north that clusters properly and goes broodless lets its core fall well below brood temperature and feeds nobody. Mild winters therefore cost stores rather than saving them. The implication is that a warm January is a reason to heft hives and be ready to feed, not to relax, and that emergency feed in the coastal plain and Gulf coastal areas should be planned for late winter, when a colony that has brooded all along is at its lowest and its demand is rising.

1.18 Further Reading

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- University of Georgia Cooperative Extension honey bee publications and the Georgia Master Beekeeper Program materials; University of Florida IFAS Honey Bee Research and Extension Laboratory fact sheets; Clemson University and NC State Extension apiculture publications for piedmont and mountain conditions; Auburn University and LSU AgCenter publications for Gulf coastal and coastal plain conditions.

Chapter 2. Colony Behavior, Communication & Social Organization

Covers exam questions Q28-Q48.

2.1 Orientation

A honey bee colony has no manager. No bee knows how much nectar is coming in, whether the brood nest is too warm, or whether the hive next door has a weak entrance worth raiding. Every colony-level decision is assembled from local information held by individuals who each see a fraction of the picture. Master-level questions in this domain rarely ask you to name a dance; they ask whether you understand the feedback loop that produces the behavior, because only that lets you run the inference backwards - from what you see at the entrance to what is happening inside.

Three ideas organize the chapter. The first is **encoding**: the colony converts information from one frame of reference into another, most famously the waggle dance's conversion of a solar bearing into an angle from gravity. Know what each signal encodes and, equally, what it cannot. Half the distractors in this domain attribute to a signal information it does not carry.

The second is **feedback and thresholds**. Foraging effort, water collection, receiver allocation and forager recruitment share one architecture: an individual experiences a delay, a concentration or a contact rate, compares it to her own threshold, and adjusts. Because individuals differ in their thresholds, the colony gets a graded response rather than an all-or-nothing switch.

The third is **behavior as evidence**. Bees hovering in arcs, bees weaving along the hive body, a curtain of bees on a July evening, a rising roar when the cover comes off, thin piping through the woodenware: each has a differential diagnosis, and the master beekeeper knows the second and third items on the list and which observation discriminates among them.

2.2 The Dance Language: What It Encodes and What It Does Not

2.2.1 The transposition from sun to gravity

A forager returning from a profitable source dances on a defined area of comb near the entrance - the dance floor - performing a waggle run: a straight burst of lateral vibration, then a looping return, alternating the side of the loop so the figure traces a flattened figure eight. The straight portion carries direction. In the dark nest the bee cannot see the sun, so gravity substitutes: **straight up on the vertical comb stands for the direction of the sun's azimuth** - the compass bearing of the point on the horizon below the sun, not its elevation. The angle of the run from vertical is the angle between that azimuth and the source, and **both the magnitude and the handedness are preserved**. A run 45 degrees left of straight up means the source lies 45 degrees left of the sun's azimuth. Nothing is mirrored, and the angle carries no distance information at all. Because gravity is the reference, a dance on a horizontal surface - the top of a swarm cluster - switches to pointing directly at the target.

2.2.2 Distance, and how the bee measures it

Distance is encoded in the **duration of the waggle portion**, not the angle, not the number of circuits, not the loudness. The working rule is roughly **one second of waggle per kilometer**. The calibration differs slightly among subspecies of *Apis mellifera* - the dialects von Frisch documented - so a bee following a dancer of another race systematically misjudges distance.

The mechanism explains the failures. The bee does not measure distance by energy spent or time in flight; she integrates **optic flow**, the total image motion swept across her eyes outbound. A bee flown down a short narrow tunnel with patterned walls dances an absurdly long distance, because close walls generate enormous flow over a short flight. Headwinds, which cost energy, do not inflate the dance proportionally, and a route over open water is under-reported for want of visual texture.

2.2.3 Round, sickle and waggle: one signal on a gradient

When the source is very close - generally **within roughly 50 to 100 meters**, the transition varying by subspecies - the bee performs a round dance: rapid circling that reverses direction, with little or no straight run, so directional information is effectively absent and recruits simply search the vicinity. As distance grows the dance acquires a short waggle segment and becomes a sickle form, and by a few hundred meters it is a full waggle dance. There are not three dances but one graded behavior in which the straight run shrinks toward zero as distance shrinks.

Open feeding, a syrup spill, or a broken burr comb on the ground creates a source at essentially zero distance. The resulting dances carry no direction, so recruits pour out and search everything within a hundred meters - during a dearth, every hive in the yard. That is one mechanism by which careless feeding starts robbing, and why a feeder belongs inside the hive it is feeding.

2.2.4 Vigor and odor

Dance vigor and persistence encode profitability, integrating sugar concentration, flow rate, distance, crowding and handling time. Because the signal is graded, recruitment is biased toward the best patches without any bee comparing patches. The recruit also gets odor - floral scent on the dancer's body and in the nectar sample shared in trophallaxis - which she uses to identify the right flower on arrival. Even so, several trips to find the source is typical and many recruits never find it.

2.2.5 The sun compass, time compensation and polarized light

The sun moves, so a solar bearing decays. Bees compensate with an **internal circadian clock** that tracks the azimuth rate, and the compensation runs continuously rather than being recomputed from a fresh look at the sky: a bee confined for hours and released orients correctly for the new sun position, and dances inside the dark nest shift their angle through the morning to track a sun the dancer cannot see. That is why scouts keep dancing on the cluster surface overnight with angles that stay correct for the sun's movement. When the swarm lifts off next morning it is guided by an informed minority of scouts that streak through the cloud in the direction of the chosen cavity.

Under cloud, bees infer the sun's position from the **pattern of polarized light in patches of blue sky**, detected by specialized ommatidia in the dorsal rim of the compound eye. The e-vector pattern is

geometrically tied to the sun, so one patch of clear sky suffices. Under full overcast this fails and bees fall back on landmarks and the brightness gradient, which is why dance recruitment degrades on heavily overcast days while experienced foragers keep working known patches.

2.3 Feedback in the Foraging System

2.3.1 Unloading delay as the colony's measure of processing capacity

A returning nectar forager does not store her own load; she hands it to a receiver, a middle-aged house bee. **How long she waits to find one samples the ratio between collection and processing capacity**, and she needs no other measure. A forager unloaded quickly - on the order of **20 seconds or less** - treats the colony as hungry for nectar and is likely to waggle dance. One who waits long - on the order of **50 seconds or more** - performs a **tremble dance**, walking erratically through the broodnest area for many minutes, body trembling, turning as she goes.

The tremble dance does two things that together fix the imbalance: it recruits additional bees into receiving, and it suppresses waggle dancing. **The principal trigger is unloading delay, not source quality.** A forager off a superb source tremble dances if nobody takes her load; one off a poor source unloaded instantly does not. Crowding at the source can also elicit tremble dancing, but widespread tremble dancing during a flow still points first to a bottleneck inside the hive. The response is super space - preferably drawn comb - and ventilation to speed ripening. A colony tremble dancing and backfilling the brood nest will start swarm cells shortly.

2.3.2 Stop signal and vibration signal: two different things

The **stop signal** is a brief vibratory pulse - a short buzz of a few hundred hertz lasting roughly a tenth to two tenths of a second - delivered by butting the head against a dancer. It **inhibits waggle dancing, aimed mainly at dancers advertising that source**. It is delivered by bees who found the advertised source crowded, depleted or dangerous, and its production rises with the danger the sender met: negative feedback aimed preferentially, though not exclusively, at the same source.

The **vibration signal** (shaking signal, dorsoventral abdominal vibration) differs in kind: a worker grasps a nestmate and vibrates her own body for about a second. It is **nonspecific and activating**, raising the receiver's general activity and readiness for whatever task is in demand. Its rate rises before swarm departure, and workers also shake the queen in the days before a swarm, associated with her reduced laying and weight loss for flight. One is a brake on a specific message, the other a general accelerator.

2.3.3 Water runs on the same feedback

Water is collected for evaporative cooling and for diluting stores to feed brood, and it is regulated by **the same unloading-latency mechanism**: a collector whose load is taken eagerly returns for more; one refused or slowly unloaded quits. Demand is expressed as receptivity. Nothing measures humidity at the entrance, the queen does not signal her needs, and no fixed fraction of foragers is permanently assigned to water. Colonies then develop fidelity to a source and keep returning even when better water appears, so the way to keep bees off a neighbor's pool is to establish an attractive source - warm, shallow, secure landing, a little algal or salt odor - in early spring, **before** fidelity forms.

2.4 Trophallaxis: the Colony's Circulatory and Chemical Network

Mouth-to-mouth exchange is continuous, and its significance is that it makes the colony's contents **rapidly homogeneous**. In the classic radiotracer demonstration, six foragers were fed syrup labeled with radiophosphorus and released into a colony of about 24,600 bees. At 4 hours, 62 percent of foragers and roughly a sixth to a fifth of all bees were labeled. At 27 hours, 76 percent of foragers and between 43 and 60 percent of all bees carried the label, and within 48 hours every one of the large unsealed larvae had received it.

Three consequences. Food is a colony-level resource, equalized across tens of thousands of bees within a day. **The same network carries chemical information**: queen mandibular pheromone picked up by retinue workers passes on in trophallactic and grooming contacts, so the queen broadcasts her presence without visiting anyone, and the colony detects her loss within about an hour because the incoming signal stops. And anything soluble you put in distributes identically - the basis of oral treatments and the route by which contaminated feed reaches the whole population including larvae. Trophallaxis is not confined to nurses feeding larvae, does not cease during a flow, and is not a transfer of digestive competence from old bees to young.

2.5 The Pheromone System as an Integrated Whole

Pheromones are conventionally split into **releaser** effects, which change behavior at once, and **primer** effects, which change physiology over days to weeks. Most important ones do both, and the skill is knowing which you are looking at.

2.5.1 Queen mandibular pheromone and the retinue

QMP is a blend whose core is five components, best known 9-ODA (9-oxo-2-decenoic acid) and 9-HDA with HOB and HVA. None works at full strength alone; they act synergistically, and further compounds identified later, including coniferyl alcohol, increase retinue attraction in combination. Workers meeting the queen turn to her, lick and antennate, then disperse carrying the pheromone.

Its effects span both categories: holding the retinue (releaser); **inhibiting worker ovary development** and **inhibiting queen cell construction** (primer); stabilizing a flying swarm; and, in 9-ODA, attracting drones at congregation areas. It also delays behavioral maturation of young workers. When a queen fails all of this lifts at once, which is why queenlessness produces a coordinated cascade: emergency cells, rising defensiveness, eventually laying workers.

2.5.2 Brood pheromones: the colony's census of its young

Brood ester pheromone (BEP) is a blend of ten fatty acid esters - methyl and ethyl palmitate, oleate, stearate, linoleate and linolenate - on the larval cuticle, the proportions shifting as larvae age and grow hungry. It is largely non-volatile and works by contact. **E-beta-ocimene** is a volatile terpene from young larvae that travels through nest air.

Effects are dose- and age-dependent and the literature is not fully settled, but the outline holds: a large amount of brood per adult holds workers in nursing roles and stimulates pollen foraging by those already foraging, while the volatile signal from young larvae pushes bees toward earlier foraging. The

colony matches pollen collection to actual brood demand rather than to a schedule - which is why a colony with a block of open brood hauls pollen hard and one just gone broodless stops overnight.

2.5.3 Nasonov, alarm and footprint pheromones

The **Nasonov gland**, on the dorsal abdomen between the last terga, releases seven terpenoids: geraniol, nerol, the two citral isomers, nerolic and geranic acids, and farnesol. The bee exposes it by raising her abdomen, flexing the tip, and fanning. It is an **aggregation and orientation signal** used at the hive entrance, at a settling swarm cluster, at a cavity a swarm is entering, and at scent-free resources such as water. It is not released at already-scented flowers, and **robbers do not release it at a target hive** - bees fanning with abdomens raised are orienting, not raiding.

The sting apparatus releases more than forty compounds dominated by **isopentyl acetate (isoamyl acetate)**, which smells of banana. It is volatile, marks the target, and arouses and recruits nestmates to that spot. Volatility cuts both ways: it spreads in seconds and dissipates in minutes, which is why a stirred colony settles if you stop working it, and why a sting left in a glove keeps working until the glove is set aside. Smoke's principal effect is to **mask this signal** and interrupt the cascade, which is why smoke applied before you rouse a colony works far better than smoke applied after.

The mandibular glands produce **2-heptanone**, long called a secondary alarm substance; that has been revised. It is secreted when a bee bites and acts as a **local anaesthetic**, paralyzing intruders such as wax moth larvae and mites too small to sting - a weapon for the small-intruder problem, not an alarm signal.

Tarsal glands leave a short-lived **footprint** trace wherever a bee walks; worker traces on flowers act as a "recently visited" mark. The queen's footprint pheromone matters more to management: deposited as she walks the lower brood nest, it **inhibits queen cell construction**. In a congested colony she cannot circulate freely, the deposit on the lower bars thins, and an inhibition lifts exactly where swarm cells appear. That, with dilution of QMP through a crowded population, is a better account of congestion-driven swarming than "the bees ran out of room," because it names what the bees actually detect.

2.6 Nestmate Recognition, Drifting and Combining

Guards discriminate nestmates from intruders using a **learned chemical template based on cuticular hydrocarbons**. Each bee's profile is strongly shaped by the wax of the comb she occupies and by the colony's forage, so it is environmental as well as genetic and drifts with season. A young bee learns the colony profile after emergence; guards challenge bees falling outside it. Recognition is of a colony odor, not of individuals, and it is not based on queen pheromone.

Everything practical follows from the label being learned and mutable. Colonies sharing comb, feed and forage smell alike and accept each other readily - which is why the **newspaper combine** works, holding the populations apart a day or two while volatiles equilibrate through the holes they chew. It is why guards are permissive during a strong flow, when a heavily laden arrival is challenged less, and strict during a dearth. And it is why identical hives in a long row all facing one way produce heavy **drifting**, which redistributes bees and with them **Varroa and the viruses those mites carry**, plus *Vairimorpha (Nosema)* spores and foulbrood organisms, so one heavily infested colony can seed the whole apiary. It also corrupts assessment: end-of-row colonies accumulate drifted bees and look strong while their

neighbors dwindle, and both readings are wrong. Because mites immigrate on drifting and robbing bees, **mite management is an apiary-level problem** - an effective treatment can be undone in weeks by immigration from an untreated colony a few feet away.

Layout measures all attack the same problem, that bees cannot tell the hives apart: break up long rows into small clusters or horseshoes; face entrances in different directions; vary colors or add large distinctive entrance markings; use irregular spacing; and site hives against landmarks - trees, posts, shrubs - that give each a unique visual address.

2.7 Division of Labor and How It Re-allocates Under Loss

Worker tasks follow age - **temporal polyethism** - but the schedule is a tendency, not a timetable. Roughly: cell cleaning days 1-2; nursing days 3-11; receiving and storing nectar, comb building, capping and ventilating about days 12-18; guarding in the late teens to about day 21; foraging from about three weeks to death. Underneath is an endocrine transition: nurses carry high **vitellogenin** and low juvenile hormone, and the switch to foraging involves vitellogenin falling and juvenile hormone rising.

What makes it robust is that the schedule is **socially regulated**, not autonomous. Foragers produce **ethyl oleate**, a primer pheromone passed to younger bees, which delays their maturation into foragers. The dose a young bee receives samples how many foragers the colony has. Remove the foragers - a pesticide kill, an excluder mishap that strands the field force, the attrition of a heavy flow - and inhibition lifts, so bees accelerate and begin foraging days earlier, sometimes at ten or twelve days old. Confine foragers indoors for a week of rain and the inhibition intensifies, holding young bees back.

Reallocation runs backwards too. Strip the nurse bees and foragers can **revert**, redeveloping hypopharyngeal glands and resuming brood feeding; reversion is slower and less complete than acceleration, but it is why a colony that lost its young bees can still rear the next cohort. Layered on all this is **response-threshold variation**: workers differ, partly by patriline, in how strong a stimulus must be before they perform a task, so low-threshold bees act first and higher-threshold bees take over as the stimulus rises. A polyandrous queen produces many patrilines and a wide spread of thresholds, giving a smooth graded response instead of a lurching one - one of the functional arguments for extreme polyandry.

2.8 Thermoregulation, Water and Bearding

The brood nest is held at about **34.5 degrees C (roughly 94 to 95 degrees F)**, working range 32 to 36. Precision matters because pupal development is temperature sensitive: brood reared cool emerges late with impaired learning and, at the extreme, deformed wings; brood reared warm emerges early with its own deficits. Heat comes from workers shivering flight muscles without moving their wings, some pressing into empty cells within the brood pattern as local heaters - one reason a frame with a few empty cells among sealed brood is not necessarily a poor pattern.

Cooling runs in stages, and the stages are the point. As nest temperature rises, workers first fan to move air; then spread thin films of water on cell rims and on their own tongues and fan across them, converting the problem to evaporative cooling and generating the demand that drives water collection;

and finally, when the bees' own metabolic heat is part of the load, **surplus bees leave the nest and hang outside**. That is **bearding**.

Bearding is normal thermoregulation, most conspicuous on hot humid evenings when the day's heat is still in the boxes and humidity has blunted evaporative cooling. It is not a swarm sign: swarms issue on warm middays, are preceded by charged queen cells, and are a mass departure, not a static curtain. For bearding, check shade, ventilation, water and whether the colony is honey-bound; for swarming, check the brood nest, bottom bars and comb faces. Distinguish both from **washboarding**, the rhythmic rocking of bees on the hive front, which has no thermal or swarm significance.

In winter the machinery reverses. Below about 57 degrees F the colony contracts into a cluster whose dense mantle insulates a loose core. Broodless, the core runs cool, well below brood temperature (roughly 18 to 32 degrees C, depending on conditions); once brood starts the core must be lifted to brood temperature and held there, which is why a cold snap that pins a brood-rearing cluster away from honey produces late-winter starvation beside full frames.

2.9 Social Immunity: Hygienic Behavior, VSH, Undertaking and Propolis

Hygienic behavior is the general ability of workers to detect, uncap and remove dead or diseased brood from sealed cells. It confers real resistance to American foulbrood and chalkbrood because it removes infected larvae before they become spore-laden and infectious. It is assessed with the **freeze-killed brood assay**: a measured patch of sealed brood is killed with liquid nitrogen or by freezing an excised section, returned to the colony, and scored at 24 hours, with **removal of about 95 percent or more** marking a hygienic colony. The pin-kill test is a cheaper approximation scored the same way.

Varroa sensitive hygiene (VSH) is narrower: detecting sealed cells containing Varroa and removing the contents, interrupting mite reproduction. In the classical account the bees preferentially remove cells with a **reproducing** foundress mite, though recent work suggests the mite's presence rather than its offspring may be the trigger. It is assessed not as a removal percentage but by opening infested sealed cells and scoring the **proportion of foundress mites that failed to reproduce**, because the successful ones have been selectively pulled and what remains is enriched for non-reproductive mites. The two traits overlap but are not interchangeable: a high freeze-killed-brood score does not guarantee strong Varroa-specific removal, so anyone breeding or buying resistant stock must know which trait was selected and by which assay.

Undertaking is corpse removal, performed by a relatively small subset of **middle-aged** workers rather than by every bee or by the oldest foragers. The trigger is **chemical, not mechanical**: changes in the corpse's cuticular chemistry after death, chiefly the fall in cuticular hydrocarbons given off as the body cools (oleic acid, the classic corpse cue in ants, has weaker support in honey bees). Corpses are removed far faster than inert debris of the same size and weight, and an anaesthetized but living bee is generally not carried out - the observation that rules out immobility as the cue. For the beekeeper, a scattering of dead bees after a cold spell is ordinary cleanout; a large pile of freshly dead bees in good weather warrants investigation of pesticide exposure, robbing or disease.

Propolis is the fourth leg. Feral colonies line the cavity with a propolis envelope, and colonies given rough interior surfaces build one in managed equipment. Workers in colonies with an envelope show **reduced baseline expression of immune-related genes** - a lower standing investment in costly individual immunity, consistent with the nest lining doing part of the antimicrobial work at colony level. That is a real argument for rough interior surfaces or propolis traps rather than scraping everything smooth, and it puts propolis alongside hygienic behavior, allogrooming and the elevation of brood-nest temperature in response to chalkbrood.

2.10 Defense, Robbing, and Reading the Entrance

2.10.1 Guarding and what modulates defensiveness

Guards are a small number of bees at the entrance, typically in the later pre-foraging period, and their number rises with threat and with dearth. A guard detecting an intruder may release alarm pheromone, which arouses nearby bees, recruits them to the source and lowers their threshold for stinging, while each sting deposits more pheromone at the same spot. Colony defensiveness is therefore a product of three separately measurable parameters: **how readily bees respond, how many respond, and how long and far they pursue**.

Defensiveness is not fixed. It rises with dearth, robbing pressure, falling barometric pressure, queen loss, predator harassment and rough handling, and it falls during a strong flow. When a colony grows steadily more defensive over weeks with no change in weather or handling, work the causes in order of likelihood and cost to check:

- **Confirm it is queenright** with a laying queen. Queenlessness commonly raises defensiveness and it is the cheapest check.
- **Determine whether the queen has changed** - is she the marked queen you introduced? A supersedure or unnoticed swarm brings in new genetics twice, through the new queen and through the drones she mated with, and temperament change is the usual first symptom.
- **Look for nighttime predator harassment.** Skunk work leaves scratch marks on the hive front, trampled vegetation and disturbed entrance debris; a colony worked over nightly is hair-triggered by day.
- **Weigh dearth and robbing pressure** in the yard, which raise guard numbers and lower thresholds across every colony.
- **Consider African introgression** through the drones the new queen mated with, in parts of the southeastern US where African-derived bees occur.

The ordering puts cheap and common before alarming and rare, and it is nearly self-correcting: the remedy for most of the list is requeening with known gentle stock, which turns the workforce over in about six weeks.

Colonies with African-derived genetics differ on the same measurable axes, and the differences are large and reproducible: a **lower response threshold**, more bees responding, **longer pursuit distances** - hundreds of meters rather than tens - more sustained arousal after the disturbance ends, and markedly

higher rates of swarming and absconding. The differences are quantitative, not categorical. A single observation cannot classify a colony, because a European colony that is queenless, robbed and prodded in a thunderstorm looks bad on every axis, and confirmation requires laboratory morphometrics or genetic analysis. But you do not need identification to act: requeening with known European stock is the practical control regardless.

2.10.2 Robbing: why it escalates

Robbing starts when a bee finds accessible stores in another colony and gets away with it. She returns, unloads quickly and recruits. The target loses defenders to fighting and its guard force is progressively overwhelmed, so the probability the next robber gets in goes **up**, not down. That is **positive feedback** - successful robbers recruit more robbers while the target's defensive capacity falls - and it continues until the target is stripped.

Because it is self-reinforcing, prevention beats response by a wide margin. Reduce entrances **before** the dearth, not during an attack; equalize colonies so none is too weak to hold its entrance; leave no wet supers, broken comb or spilled syrup exposed; feed inside the hive during a dearth; and keep inspections short when there is no flow. Once robbing starts, reduce the entrance to a single bee space, fit a robbing screen that displaces the entrance so robbers orienting to the scent cannot find the way in, throw a wet sheet over the hive, or remove the target from the apiary. Two myths need clearing: robbers do not fan Nasonov at the target, and robbing is not directed by the queen or driven by alarm pheromone spreading across the yard - alarm pheromone mobilizes defense, it does not recruit raiders.

2.10.3 Orientation flights versus robbing versus normal traffic

Feature	Orientation flights	Robbing
Flight pattern	Facing the hive, hovering in slowly widening arcs	Fast, weaving, searching flight along the hive body
Where they go	In and out of the entrance normally	Probing cracks, seams, corners, under the lid
Fighting	None	Wrestling pairs on the landing board and on the ground
Dead bees	None beyond normal	Accumulating in front of the hive
Debris	None	Wax flecks and torn cappings on the board and below the entrance
Timing	Early to mid afternoon, warm day, often after a rain-bound spell	Any flying hour during a dearth; intensifies through the day
Whose bees	All belong to that colony	Bees from other colonies, often shiny and hairless from being chewed
Response	None needed	Immediate: reduce entrance, remove exposed feed and comb

Normal foraging traffic differs from both: directional and purposeful, bees leaving unladen and returning with distended abdomens or pollen loads, entering without hesitation and without challenge. A stream of shiny, dark, nearly hairless bees weaving at the seams in August is not a flow.

2.11 Nest-Site Selection and Quorum Sensing

A clustered swarm must choose a cavity fast, because it is exposed and carries only the honey in the bees' crops. A few hundred scouts - experienced older foragers, a small fraction of the swarm - search independently over several kilometers. A scout who finds a candidate inspects it thoroughly, walking the interior and making orientation flights outside, assessing volume, entrance size and height, exposure and prior occupancy. Colonies favor cavities of roughly **40 liters** (about 15 liters as a practical minimum), with a small entrance of about **10 to 30 square centimeters** set low in the cavity, several meters above ground, weathertight, and previously occupied by bees.

She returns and **dances on the surface of the cluster**, with vigor and number of circuits proportional to the quality she assessed. Other scouts follow, fly out, inspect **independently**, and dance for the site in turn if they judge it good. Three properties make this converge:

- **Dance decay.** Each time a scout returns from a site she dances somewhat less than before, so support for a site nobody else endorses fades. Only a site that keeps recruiting new endorsers holds its constituency: poorer sites lose support, better ones accumulate it.
- **Independent assessment.** Recruits judge the cavity themselves rather than taking the dancer's word, so this is not a popularity contest.
- **Cross-inhibition.** Scouts deliver **stop signals** to bees dancing for competing sites, accelerating the collapse of losing options.

The decision is made by **quorum**, not consensus. When the number of scouts simultaneously present **at one site** reaches roughly **10 to 20 bees** (some swarms needed more), those scouts stop assessing, return to the cluster and begin **worker piping**, running through the cluster and signaling the bees to warm their flight muscles; piping builds over roughly the last hour, and the swarm lifts off once the whole cluster is warm. Note what the quorum buys: no bee ever compares all the options, and the swarm does not wait for agreement. It waits for one option to attract enough independent endorsements - a fast proxy for quality, and a defensible trade of a little accuracy for a great deal of speed.

2.12 Reading Queen State from Behavior and Sound

2.12.1 Tooting and quacking

Queen piping is audible through the hive wall but reaches the bees as **comb vibration**, not airborne sound. Fundamental frequency rises with queen age and spans roughly **350 to 550 Hz**. **Tooting** is produced by a free virgin standing with her thorax pressed to the comb: an opening syllable of about a second followed by progressively shorter ones. **Quacking** comes from mature virgins still confined in their cells, in short pulses of about a tenth of a second, usually answering tooting.

Hearing both means a **free virgin is loose and other mature virgins are still in their cells** - which normally means the primary swarm has already issued and the colony is set to throw afterswarms. Swarm prevention is finished; the question is damage control. Reduce the remaining cells to a single good one, or destroy all cells and introduce a mated queen, so the colony does not cast a succession of afterswarms and fall below viable strength.

2.12.2 Recognizing queenlessness

A colony queenless several days but still holding young larvae shows a recognizable syndrome: a **rising roar** on opening rather than an even hum, agitated bees running on the comb faces, **no eggs**, a youngest-brood age that gets older each day you look, **emergency cells** raised on the comb face over former worker cells, and often increased defensiveness.

Two other pictures get confused with it. **Multiple eggs per cell, placed on cell walls rather than centered at the base, with drone brood in worker cells**, is **laying workers** - a much later stage, after all open brood is gone and pheromonal inhibition of worker ovaries has lapsed. **Single centered eggs in worker cells but all brood capping over as drones**, in a colony of normal demeanor, is a **drone-laying queen**: laying properly but out of sperm or poorly mated.

No single sign is conclusive, and a queen can be present and unfindable. The definitive test is a **test frame** of eggs and very young larvae from a healthy colony: a truly queenless colony starts emergency cells on it within a few days; a queenright one does not.

2.13 Absconding: When the Whole Colony Leaves

Absconding is the departure of the entire adult population, typically abandoning brood and stores, in response to conditions the bees find intolerable. It is not reproductive and produces no increase - the essential contrast with swarming, which divides the colony, takes roughly half to two-thirds of the bees plus the laying queen, and leaves a viable remnant with brood, stores and queen cells. An absconding colony leaves nothing but comb and abandoned brood.

In the southeastern US the common triggers are severe **small hive beetle** infestation and slimed comb; heavy **wax moth** destruction; **starvation** in the midsummer dearth; **extreme heat** in an unshaded apiary, especially without water; sustained **ant pressure**; and repeated heavy disturbance. Finding an empty hive with brood left in the combs should send you looking for the stressor rather than recording a swarm - and because the stressor is usually environmental and shared, it is very likely acting on the other colonies in the yard.

2.14 Numbers to Know Cold

Figure	Value	Why it is that value
Waggle run distance calibration	Roughly 1 second of waggle per km	Duration scales with integrated optic flow outbound; calibration differs slightly among subspecies (dialects)
Round-to-waggle transition	Roughly 50-100 m, subspecies dependent	Below this the straight run shrinks toward zero and direction cannot be resolved

Figure	Value	Why it is that value
Direction reference	Straight up on comb = solar azimuth	Gravity substitutes for the invisible sun; angle magnitude and handedness both preserved
Unloading wait favoring waggle dancing	About 20 seconds or less	Idle receivers mean more collection is useful
Unloading wait triggering tremble dancing	About 50 seconds or more	A long wait means processing, not collection, is the bottleneck
Stop signal	Roughly 0.1-0.2 s pulse, a few hundred Hz	Head-butted at a dancer; inhibits dancing, aimed mainly at the same source
Trophallaxis spread (tracer study)	6 labeled foragers into ~24,600 bees; 62% of foragers at 4 h; 76% of foragers and 43-60% of all bees at 27 h; all large unsealed larvae by 48 h	Continuous exchange homogenizes crop contents within a day
Brood nest temperature	About 34.5 degrees C (94-95 degrees F), range 32-36	Cool brood emerges late with impaired learning and deformed wings; warm brood early with its own deficits
Cluster formation temperature	Below about 57 degrees F	Flight and comb movement fail; heat must be conserved collectively
Queen piping	Roughly 350-550 Hz, rising with age. Tooting: opening syllable about 1 s then about 0.25 s. Quacking: pulses about 0.1 s	Transmitted as comb vibration; tooting from a free virgin, quacking from virgins still in cells
Nest-site quorum	About 10-20 scouts simultaneously at one site	A fast proxy for accumulated independent endorsement; trades accuracy for the speed an exposed swarm needs
Preferred cavity	About 40 liters (15 liters minimum); entrance about 10-30 square cm, low in the cavity, several meters up	Enough for winter stores without excessive heating cost; a small entrance, near the cavity floor but well above ground, is defensible and thermally sealable
Freeze-killed brood threshold	95 percent or more removed in 24 hours	The rate at which removal outpaces development of infectious spore loads
VSH assessment	Proportion of foundress mites non-reproductive in sealed cells	Measures the trait directly; in the classical account reproducing foundresses are the ones removed
Temporal polyethism outline	Cleaning d1-2; nursing d3-11;	Vitellogenin falling and juvenile hormone rising, modulated by social signals, not a fixed timetable

Figure	Value	Why it is that value
	receiving/wax/ventilating d12-18; guarding to about d21; foraging after	
QMP core components	Five, centered on 9-ODA and 9-HDA with HOB and HVA	Synergistic; no single component reproduces the full effect
Brood ester pheromone	10 fatty acid esters (methyl and ethyl palmitate, oleate, stearate, linoleate, linolenate)	Non-volatile contact signal whose blend shifts with larval age and hunger
Nasonov pheromone	7 terpenoids: geraniol, nerol, E- and Z-citral, nerolic acid, geranic acid, farnesol	Aggregation signal for scent-free targets: entrance, cluster, water
Principal sting alarm component	Isopentyl (isoamyl) acetate, among 40-plus compounds	Spreads in seconds and dissipates in minutes; smoke masks it
Requeening turnover	About 6 weeks to change colony temperament	The existing workforce must die out and be replaced by the new queen's daughters

2.15 Common Misconceptions

Misconception: The angle of the waggle run gives distance and the length of the run gives direction. **Correction:** Exactly backwards. The angle from vertical encodes direction relative to the sun's azimuth, preserving both size and handedness; waggle duration encodes distance at roughly a second per kilometer. Vigor and persistence encode profitability, and nothing encodes richness in the angle.

Misconception: A tremble dance means the forager found something wrong at the flower - a predator, a competitor, an exhausted patch. **Correction:** The principal trigger is a long wait to be unloaded by a receiver, not source quality; crowding at the source can also elicit it. A forager off a superb source tremble dances if nobody takes her load. The dance recruits receivers and damps waggle dancing, fixing a processing bottleneck. The signal that cancels recruitment to a specific bad location is the stop signal, a different thing entirely.

Misconception: Bees can only use the dance when the sun is out, so recruitment stops under cloud. **Correction:** They infer the sun's position from the polarization pattern of any visible patch of blue sky, using dorsal-rim ommatidia, and hold that position by an internal clock across periods of confinement - which is why scouts dancing on an overnight cluster keep their dance angles correct for the sun's movement. Full overcast degrades recruitment but does not stop established foragers.

Misconception: Guards recognize nestmates by the queen's pheromone, or by an innate tag fixed at emergence. **Correction:** Recognition uses a learned template of cuticular hydrocarbons, heavily

influenced by comb wax and forage, so it drifts with season. That is why shared comb and diet make colonies mutually acceptable, why the newspaper combine works, and why guards relax during a flow and tighten during a dearth.

Misconception: A big beard on a hot evening means the colony is about to swarm. **Correction:** Evening bearding in hot, humid weather is ordinary thermoregulation - surplus bees move outside so their own metabolic heat stops adding to the load. Swarms leave on warm middays, are preceded by charged queen cells, and depart as a mass. Check shade, ventilation and water for bearding; check the brood nest for swarming.

Misconception: Robbing bees release Nasonov at the target hive to call in more robbers. **Correction:** Nasonov is an aggregation signal for nestmates at a scent-free target: the home entrance, a settling swarm, a new cavity, water. Robbing escalates because successful robbers recruit more robbers while the target loses defenders - positive feedback, not pheromonal marking.

Misconception: Undertakers carry out anything that lies still, so an anaesthetized bee gets removed like a corpse. **Correction:** The cue is chemical, not mechanical: the change in cuticular chemistry after death, which is why there is a lag and why anaesthetized but living bees generally stay put. Undertaking is also done by a modest subset of middle-aged workers, not by every bee and not by the oldest foragers.

Misconception: Hygienic behavior and VSH are the same trait, so a high freeze-killed brood score means mite resistance. **Correction:** They are related but distinct behaviors, selected and measured differently; whether they share a genetic basis is not settled. The freeze-killed assay measures general removal of dead sealed brood and predicts resistance to American foulbrood and chalkbrood. VSH is the specific removal of cells containing Varroa, classically those with reproducing mites, measured as the proportion of non-reproductive foundresses. A colony can score well on one and poorly on the other.

Misconception: Propolis is a nuisance to be scraped off every surface. **Correction:** A propolis envelope reduces baseline expression of immune-related genes in workers - the colony spends less on costly individual immunity because the nest lining does antimicrobial work. Scraping everything smooth trades a real colony-level defense for easier manipulation.

Misconception: Tooting and quacking mean two mated queens are about to fight, or that the colony is going queenless. **Correction:** It means virgins - a free virgin tooting and mature virgins still sealed quacking. In nearly all cases the primary swarm has already gone. Prevention is over; the decision is whether to leave a single good cell or destroy all cells and introduce a mated queen, to stop a run of afterswarms.

Misconception: Water collection is regulated by sensing humidity, or by a standing allocation of water foragers. **Correction:** It runs on the same unloading-latency feedback as nectar: a collector taken up eagerly returns, one refused quits. Demand is expressed as receptivity. Practically, this is why bees keep visiting a pool they have imprinted on, and why you must supply an attractive source before that fidelity forms.

Misconception: A colony that suddenly turns mean must have African genetics. **Correction:** Work the differential in order: queenlessness, an unnoticed queen change, skunk or other night harassment,

dearth and robbing pressure - then introgression. African-derived colonies genuinely differ in threshold, numbers responding, pursuit distance and duration of arousal, but the differences are quantitative and one observation cannot classify a colony.

Misconception: A hive found empty with brood left in the combs has swarmed. **Correction:** Swarming leaves a viable remnant - bees, brood, stores and queen cells. An empty box with abandoned brood is absconding, a response to an intolerable condition: beetle slime, wax moth, starvation, extreme heat without shade or water, ants, or repeated disturbance. Find the stressor, because it is probably acting on the neighbors too.

2.16 Self-Check Questions

- A forager dances a run angled 30 degrees to the right of straight *down* on the comb, with a waggle portion of about 2.5 seconds. Where is the source, and how confident are you in the distance?
- Explain why a bee flown through a short, narrow, patterned tunnel dances a much longer distance than she flew, and what that reveals about the odometer.
- Distinguish the stop signal from the vibration (shaking) signal by trigger, specificity and effect.
- You find widespread tremble dancing during a heavy spring flow. What is the colony telling you, what is it not telling you, and what do you do?
- Give the mechanism by which a colony knows within about an hour that its queen has been removed.
- Using the classic tracer results, how long before an oral product fed in syrup reaches the brood, and what caution follows from the same mechanism?
- A swarm clustered for a day departs on an accurate bearing to a cavity nobody flew to that morning. Explain both the navigational and the decision mechanisms, including the role of the quorum.
- Your end-of-row colony in a straight row of eight identical white hives is booming while its neighbor two positions in is dwindling, and mite counts are climbing in both. Explain the link and give four layout changes.
- You hear thin piping through the hive wall in early June; on opening you find several sealed queen cells and a much reduced population. What is the piping, what has already happened, and what are your two defensible options?
- Explain why the freeze-killed brood assay does not tell you whether a colony will control Varroa, and describe what you would measure instead.
- A colony requeened in April with a marked queen has become steadily more defensive over six weeks in a July dearth. Give your investigation in order and justify the ordering.

2.17 Self-Check Answers

- Straight down is the direction away from the sun's azimuth, so the source lies 150 degrees to the right of the sun's azimuth, 30 degrees short of the anti-solar direction. At roughly a second per kilometer, 2.5 seconds implies about 2.5 km. Confidence in distance is moderate: calibration varies among subspecies, individual runs scatter, and the bee reports integrated optic flow rather than ground distance, so a route over water or bare ground is under-reported.

- The odometer integrates image motion across the eye, not energy spent or time elapsed. Close tunnel walls generate in a short flight the flow a long open flight would produce, so the bee reports a long distance. The encoded quantity is visual, not metabolic - which is why headwinds do not inflate the dance in proportion to effort and why the dance is reliable within the landscape the bees learned rather than as an absolute measure.

- The stop signal is a brief vibratory pulse, about a tenth to two tenths of a second, delivered by butting a dancer; it is triggered by a bad experience at the advertised source, rises with the danger met, and inhibits dancing mainly for that source. The vibration signal is a worker grasping a nestmate and vibrating for about a second; it is nonspecific, raises general activity and readiness for whatever task is in demand, and rises before swarm departure. A targeted brake versus a general accelerator.

- Tremble dancing is mainly triggered by long waits to find a receiver, so processing and storage capacity, not foraging capacity, is limiting. It says nothing about source quality, forage or disease. Act on the bottleneck: add super space, preferably drawn comb, and improve ventilation to speed ripening. Also inspect the brood nest, because a colony that cannot place incoming nectar backfills it and moves toward swarm preparation.

- Queen mandibular pheromone is picked up by retinue workers who lick and antennate the queen, then carried on their bodies and passed through the colony by trophallaxis and grooming, so every bee receives a continuous low dose. The colony does not detect the queen; it detects the ongoing arrival of her pheromone, and what matters is its cessation. Because the trophallactic network turns contents over within hours, concentration falls measurably within roughly half an hour to an hour of removal.

- The tracer work fed labeled syrup to six foragers in a colony of about 24,600 bees: 62 percent of foragers labeled at 4 hours, 76 percent of foragers and 43 to 60 percent of all bees at 27 hours, every large unsealed larva by 48 hours. So an oral product reaches the brood within about a day and the colony within two. The caution is symmetrical: a contaminant in feed distributes just as fast and just as universally, including into larvae.

- Navigationally, scouts keep dancing on the cluster overnight and the circadian clock keeps their dance angles correct for the sun's movement, but once the swarm lifts off it is guided by an informed minority of scouts that streak through the cloud in the direction of the chosen cavity. Decision-wise, scouts danced for competing sites, each recruit assessed independently, dances decayed unless renewed, and stop signals suppressed rivals. When about 10 to 20 scouts were simultaneously present at one cavity the quorum was met; those scouts returned and piped, warming the swarm to flight readiness, and the cluster lifted off.

- Bees cannot tell identical hives in a row apart, so foragers drift toward the ends and downwind. Drifting redistributes bees and with them Varroa and the viruses those mites carry, which is why

mite load equalizes across the yard and why a treatment gets undone by immigration from neighbors. It also inflates the apparent strength of end hives at their neighbors' expense. Break the row into clusters or a horseshoe, face entrances in different directions, vary colors or add large entrance markings, use irregular spacing, and site hives against landmarks.

- Thin piping with sealed cells and a reduced population is virgin queen piping - tooting from a free virgin, and if you hear answering short pulses, quacking from virgins still in cells. The primary swarm has already issued, so prevention is no longer available. The two defensible options are to reduce cells to a single good one and accept the delay while she mates, or destroy all cells and introduce a mated queen. Either prevents a succession of afterswarms from cutting the colony below viable strength.

- The freeze-killed assay measures general removal of dead sealed brood, the trait conferring resistance to American foulbrood and chalkbrood; 95 percent or better at 24 hours marks a hygienic colony. VSH is related but narrower, and whether the two share a genetic basis is not settled: detection and removal of cells containing Varroa, classically those with a reproducing foundress. Assess it by opening infested sealed cells and scoring the proportion of foundress mites that failed to reproduce, since the reproducing ones have been selectively removed.

- First confirm she is queenright with a laying queen, since queenlessness raises defensiveness and it is the cheapest check. Second, look for the mark: an unmarked queen means a supersedure or unseen swarm has changed the genetics through both the queen and her drones. Third, look for skunk sign - scratches, trampled vegetation, disturbed entrance debris - since nightly harassment leaves a colony hair-triggered. Fourth, weigh dearth and robbing pressure, which raise defensiveness across the whole yard. Fifth, consider African introgression through the mating drones. Cheap and common before rare and alarming.

2.18 Further Reading

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- Cooperative extension apiculture publications from the University of Georgia, Clemson University, University of Florida IFAS, NC State Extension, Auburn University and the LSU AgCenter - in particular their bulletins on robbing prevention, small hive beetle and defensive colony management, and NC State Extension's free summary of honey bee dance language.

Chapter 3. Queen Biology, Mating & Rearing

Covers exam questions Q49-Q71.

3.1 Orientation

A colony is a queen plus the population she can build, and most failures blamed on weather or luck trace back through the queen to a decision about larval age, mating weather, shipping temperature or introduction technique. The examiner is not testing whether you can find a queen, but whether you understand what fixed her capacities and why they cannot be repaired afterward.

Three ideas organize the chapter. First, **caste is made by feeding and the window closes early**. A fertilized egg is bipotent; diet over roughly the first three days of larval life decides queen or worker. Ovariole number, spermatheca size and body mass are built in that window and cannot be enlarged later, which is why larval age at grafting is the most consequential choice in queen rearing.

Second, **a queen's sperm supply is a one-time acquisition**. She fills her spermatheca over a few days and never adds to it. Heat in a shipping box, cold in a truck, age and pathogens are all subtraction from an account that takes no deposits.

Third, **a queen is judged by her colony, not her appearance**. The laboratory measures of queen quality are unavailable in the field, where the only honest instrument is the brood she produces over weeks, read against the confounders that spoil a pattern with a sound queen present.

A regional theme runs underneath. The southeastern US has a long season and drones fly early and late here, making both early-spring rearing and late-summer requeening practical in the coastal plain and piedmont. The same warmth brings dearth robbing, small hive beetle and heat, which fall hardest on the small units queen work depends on.

3.2 Caste Determination: Making a Queen Out of a Female Egg

Nurse bees feed all young larvae on hypopharyngeal and mandibular gland secretions. What differs between castes is the *ratio* of the two, the total quantity, and how long the rich regime lasts. Queen larvae are fed continuously and to excess on a mixture far richer in mandibular secretion – the white, acidic component carrying 10-hydroxy-2-decenoic acid – and much higher in sugar in the later instars. Worker larvae get a progressively diluted jelly supplemented from the third day with pollen and honey.

Three mechanistic strands connect diet to phenotype. **Nutritional signaling and juvenile hormone**: high sugar drives a very high feeding rate, which drives nutrient-sensing pathways that raise JH titers during the critical period; elevated JH suppresses the programmed cell death that in worker larvae destroys most developing ovarioles, and redirects development toward larger body size, a functional spermatheca and a different gland set. This is the best-supported strand. **Epigenetic regulation**: diet-driven DNA methylation differences mark the two trajectories, and silencing the methyltransferase gene *Dnmt3* in young larvae produces queen-like adults on a worker diet (Kucharski and colleagues, 2008). **Phytochemicals in the worker diet**: royal jelly is essentially pure glandular secretion, while worker jelly supplemented with beebread carries plant compounds including p-coumaric acid that alter caste-

associated gene expression (Mao, Schuler and Berenbaum, 2015). The worker diet is not merely poorer – it carries signals the queen diet lacks.

The contested claim is that a single protein does the work. A 2011 report identified an MRJP1-derived protein, “royalactin,” as the queen-inducing factor; a 2016 paper in the same journal failed to reproduce the central result. The defensible position is that caste determination is a multi-factor nutritional switch – quantity, composition, duration and phytochemical content acting through JH and epigenetic machinery – with no single queen-making substance established.

Bipotency does not last. A larva can still be diverted for roughly the first three days of larval life, and the earlier the better. A three- or four-day-old larva has spent most of its feeding phase on a worker regime; a colony will build an emergency cell over it, but the adult is an intermediate – lighter, fewer ovarioles, smaller spermatheca, shorter useful life. The finished queen carries roughly 100 to 180 ovarioles per ovary, 300 or more in total, against two to twelve in a worker, plus a spermatheca above about a millimeter across, mandibular glands elaborated into the source of queen mandibular pheromone, no wax glands, and a smooth unbarbed sting.

3.3 Development Timing and Why Grafting Age Matters

Stage	Queen	Worker	Drone
Egg	3 days	3 days	3 days
Larva, uncapped	about 5.5 days	about 6 days	about 6.5 days
Capped on day	about 8	about 9	about 10
Emergence from egg	about 16	21	24
Sexual maturity after emergence	5-6 days	n/a	12-16 days

The queen develops *faster*, emerging five days ahead of a worker from an identical egg, because the richer diet drives a higher growth rate and an earlier cascade to pupation. That speed is why a queenless colony can have a replacement emerging in eleven or twelve days, and why the first virgin out of a bank of cells destroys her sisters within hours.

Rearing arithmetic runs from the graft. A larva about one day old is already four days past the laying of the egg, so from grafting the cell is **capped four to five days later**, the queen **emerges eleven to twelve days later**, and the handling day is **day 10**, when cells go to mating nuclei or an incubator. Day 10 is not arbitrary: earlier, the queen is in a pupal stage genuinely vulnerable to chilling and mechanical shock, and a jolt produces a deformed or dead queen with no warning until she fails to emerge; later than day 11 and you risk an emergence in the finisher, which costs every other cell on the bar. Cells travel upright and warm – an incubator runs near 93 to 95 degrees F with moderate humidity – and in a southeastern summer the danger is not chilling but a closed vehicle, where interior temperature passes anything a queen pupa survives within minutes.

Queens reared from older larvae are lighter, carry fewer ovarioles, store less sperm and are superseded more often, because the duration of queen-type feeding *before* the pathways diverge sets the ceiling, and ovarioles lost to programmed cell death are not restored by later feeding. The controls come down to knowing the age of what you pick up. **Confine the breeder queen** on an empty comb for a day; four days later every larva on it is within twenty-four hours of the same age. **Graft in good light with magnification**, since a twelve-hour and a thirty-six-hour larva are indistinguishable to an unaided middle-aged eye. **Protect the larva in transfer**, because chilling and desiccation both kill. And **prime the cups** with royal jelly diluted about half with warm water, or **double graft** – graft a sacrificial larva, let the bees provision the cell, then replace it with the one you want. Both raise acceptance and early nutrition.

3.4 Mating Biology: Drones, Congregation Areas and the Nuptial Flights

A drone congregation area is a specific volume of air, typically ten to forty meters above the ground, to which drones fly on warm afternoons and in which mating is generally assumed to occur, although queens have never been tracked on their flights. Four properties matter. They are **aerial** – no mating happens on the ground or in the hive. They are **persistent**, they tend to recur at the same landscape features, in documented cases for decades, used by successive generations that never met their predecessors; the exact position can drift by around two hundred meters, none are found in some flat landscapes, and the cause is not settled, though topography and horizon profile are associated with location. They **draw from a wide radius**: drones commonly fly two to five kilometers and further, and thousands of drones from hundreds of colonies, including feral ones, may pass through one site in a day. And **sib-mating is reduced by mixing**: drones from many colonies, often kilometers away, converge on the same sites, which biases against a queen meeting her own brothers. How far queens fly is poorly documented, because queens have never been tracked on mating flights.

The consequence is blunt: **open mating is not controlled mating.** You control the maternal line and nothing else. Flooding an area with your own drones shifts the odds of paternity; it never determines them. This is the mechanism behind the universal observation that purchased selected genetics do not persist in open-mated daughters. Real control requires instrumental insemination or isolation measured in tens of kilometers or by water, and in the settled southeastern landscape true isolation is effectively unavailable.

A virgin matures about five to six days after emergence, takes orientation flights, then mating flights on warm calm afternoons. Cool air, wind and rain suppress flight; below roughly 68 degrees F (20 degrees C) mating flights become scarce, because drones seldom fly. She mates in flight with about twelve drones on average, with a wide range, usually across one to three mating flights over one to several days. A drone that reaches her everts his endophallus, transfers semen and dies; part of the apparatus remains as the mating sign, displaced by the next drone. Flights typically run ten to thirty minutes, and she begins laying within a day or two of the last one. If weather grounds a virgin past about three weeks from emergence, she typically begins laying anyway – unfertilized eggs only – and the colony has a drone layer from the start. That is why a cold wet fortnight in the middle of a rearing run produces a whole cohort of worthless queens.

Drones need about twenty-four days from egg to emergence and a further twelve to sixteen days to sexual maturity: **thirty-six to forty days, call it six weeks**, before you add time for a drone mother to fill drone comb. The error to guard against is transposing the queen's sixteen days and few days of maturation onto the drone, which understates the lead time by roughly three weeks – exactly enough to leave virgins flying into an area stocked with somebody else's drones.

3.5 Polyandry, Effective Paternity and What Diversity Buys

Because a queen mates with many drones, a colony is a collection of patrilines rather than a family of full sisters. Workers sharing a father are supersisters related by about 0.75, because the haploid drone gives every daughter an identical paternal genome; workers of different patrilines are half sisters at about 0.25.

Effective paternity is not the count of drones she mated with. Drones contribute unequally to the sperm actually stored and used, so a queen observed to mate with twenty may have an effective paternity well below that. It is estimated by genotyping a sample of her workers and correcting for sampling error, and it is the figure that predicts colony-level consequences.

Diversity buys **thermoregulatory stability**, because patrilines differ in the temperature at which individuals begin fanning or clustering, giving a diverse colony a graded response instead of a mass switch that makes the nest oscillate (Jones, Myerscough, Graham and Oldroyd, 2004). It buys a broader **division of labor** by the same threshold logic. It buys **disease and parasite resistance**: Delaplane and colleagues found colonies headed by queens inseminated with semen from thirty or sixty drones produced significantly more brood per bee and had fewer samples positive for *Varroa destructor* than colonies at fifteen drones, showing the benefits continue past the species-typical mating frequency. And it buys **productivity and survival** (Mattila and Seeley, 2007). The inference beekeepers miss: a queen that met three drones in a bad week may lay a solid pattern for a season and still head a colony that thermoregulates poorly and builds up sluggishly. Diversity is invisible on a frame.

3.6 The Spermatheca: A Fixed Account That Cannot Be Topped Up

The spermatheca is a sphere roughly a millimeter and more across, holding about a microliter, wrapped in a dense tracheal net and served by a spermathecal gland. Keeping several million cells alive and motile for years requires a low-oxygen, antioxidant-rich environment that suppresses metabolism and limits oxidative damage.

Hold the quantities precisely. Each drone delivers on the order of **ten million** spermatozoa. Across a mating sequence a queen receives **tens of millions** – commonly cited as fifty to a hundred million or more – into her lateral oviducts. Only a fraction migrates into the spermatheca; the rest is expelled within a day or two. The stored figure for a well-mated queen is **about five to seven million**, her entire lifetime supply. A large survey of commercially produced queens found a mean near four million with a very wide range. She spends it economically, a median of about two sperm per fertilized egg (more in young queens), which is why a few million sperm can last a queen's whole laying life. But the account only goes one way.

Poor mating is the simplest damage: weather kept her grounded, or she met too few drones. **Age** does the rest – even a well-mated queen loses viable sperm over time, and in a southeastern colony laying eleven months a year, a queen in her third season is a failure candidate on that ground alone.

Thermal damage in transit is the insidious one. McAfee and colleagues established a safe zone of roughly **59 to 100 degrees F for two-to-four-hour exposures**, outside which stored sperm viability falls; a viability drop of about **11.5 percent** was the figure associated with queen failure in the field. Tracked commercial shipments recorded packages spiking to 100 degrees F and others dropping near 39 degrees F, none of them timed to extreme weather. Pettis and colleagues independently linked colony failure to low stored sperm viability. The exam point is that **thermal damage leaves no outward sign**: a heat-shocked queen is not discolored, undersized or sluggish, but looks normal, is accepted, lays well for weeks, then produces patchy or drone-heavy brood or is superseded. Since you cannot screen for it, the controls are preventive – collect queens promptly rather than leaving them on a loading dock, never leave them in a parked vehicle, hold them at moderate indoor temperature out of sun, and introduce without long delay.

3.7 Why Queens Fail, and How to Read It on the Comb

Cause	Mechanism	Field signature	Control
Poor mating weather	Too few drones met	Drone-heavy brood within weeks	Time rearing to settled weather and drone availability
Thermal damage in transit	Stored sperm killed by heat or cold	None visible; failure weeks later	Prompt collection, moderate holding, no parked vehicles
Sperm depletion with age	Fixed supply exhausted	Rising drone brood in worker cells	Requeen on a one- to two-year cycle
Nosema infection	Midgut infection, altered queen physiology	None visible; microscopy required	Low-spore colonies for escorts and bank bees
Varroa and viruses in the rearing colony	Compromised development	Whole batches underperform	Mite control in breeders, builders and nucs
Contaminated pollen in the builder	Reduced jelly quality	Low acceptance, light queens, low sperm viability	Comb rotation; clean wax and pollen
Handling injury	Damage during marking, clipping, caging	Supersedure within weeks of handling	Handle deliberately; accept the risk knowingly
Sex-locus inbreeding	Diploid drone larvae removed by nurses	Shotgun pattern from her first cycle	Source from a broad breeding population

Vairimorpha (Nosema) ceranae can infect the queen's midgut. Infected queens show altered physiology, including shifts in vitellogenin and mandibular pheromone levels, and infection has been linked to supersedure, with no reliable external sign, so diagnosis requires microscopy. The operationally useful

point is transmission: a caged queen is fed by attendants through the screen, so **escort bees for cages and banks should come from colonies with low spore counts**.

The chemical story is more contested than beekeepers assume. Miticide residues in wax, coumaphos and tau-fluvalinate especially, have long been associated with queen failure. But a 2021 study exposing adult queens topically to six wax-typical pesticides at up to thirty-two times realistic levels found no effect on queen mass, sperm viability or fat body protein expression, and its authors argued the field associations are driven by *indirect* effects on worker physiology and queen care. Companion work found contaminated *pollen* fed to rearing colonies reduced viable queen production and lowered sperm viability in the resulting queens, while contaminated *wax* alone produced no measurable phenotype. Residues matter, but the pathway runs mainly through the nurse bees and the jelly they make, so the control is comb rotation and clean wax and pollen in builders and drone mothers.

3.7.1 Drone layer versus laying workers

A **failing queen** lays normally: single eggs centered on the cell floor, because she still measures the cell with her forelegs. What has changed is that a proportion of eggs go unfertilized, because stored sperm is depleted or dead. Unfertilized eggs become drones, and a drone larva in a worker-sized cell forces a raised, domed cap – bullet brood on worker comb. Find and remove her, then introduce a queen or cell.

Laying workers arise when a colony has been queenless long enough for worker ovaries to activate in the absence of queen and open-brood pheromone. They lay multiple eggs per cell, placed erratically and often on the cell walls rather than centered, because a worker's abdomen cannot reach the base. Critically, workers with activated ovaries behave in some respects as though the colony were queenright, and such a colony typically balls and kills an introduced queen. The reliable remedy is **combining with a strong queenright colony**, which recovers bees and equipment. Shaking the laying-worker bees out in front of that colony, so that they drift in and are accepted a few at a time, is more reliable than a straight newspaper combine, in which the laying-worker bees may attack the receiving colony's queen; a newspaper combine needs an extended mixing period. Repeated frames of open brood at weekly intervals suppress ovary development more slowly. Often the soundest judgment is that the unit is not worth rescuing on its own.

3.7.2 Supersedure as an integrated assessment

Colonies do not respond to one cue. The decision integrates declining mandibular pheromone output, a falling egg-laying rate, and reduced deposition of tarsal or footprint pheromone as the queen moves over the comb. Because it is integrated, anything that degrades a queen can precipitate it: injury, disease, poor mating, thermal damage, or age. This is why supersedure so often follows rough handling, and why "she was laying fine last month" is not evidence against a supersedure attempt.

3.8 Queen Rearing Methods: Grafting and the Alternatives

Grafting lifts a young larva from a worker cell into a plastic or wax cup on a bar. It offers throughput, precise control of larval age and cells that detach cleanly, at the cost of skill and eyesight.

The **cell punch** removes the transfer: a cylindrical punch takes a plug of comb with the larva undisturbed in its own jelly, and the plug mounts in a holder on a cell bar. Acceptance is good and the larva is never touched, but it consumes comb and is slower per cell.

The **Miller** method needs no transfer at all. Strips of foundation with jagged lower edges are drawn out and laid in by the breeder queen, then trimmed back to a line of very young larvae along an exposed edge and given to a queenless builder, which draws cells from the exposed margin. The **Hopkins** method thins a comb of very young larvae so isolated survivors remain at intervals, then lays it **horizontally** above a queenless colony, which builds cells downward from the underside. Both work on the same principle as grafting – presenting very young larvae where bees can build cells from them – without transfer by the beekeeper. They suit those who cannot handle a twelve-hour larva, at the cost of awkward harvesting, since cells must be cut from comb rather than lifted off a bar. Modern cell-cup systems reach the same end by confining the queen to lay directly into removable plastic cell bases.

The **on-the-spot or notching** method is simplest. Identify a comb carrying larvae of verified young age, then use a hive tool to notch or scrape away the lower wall of a row of cells, exposing those larvae along a cut edge. In a colony made queenless, the bees preferentially build cells from the exposed larvae at the notch. You get control over larval age, and therefore queen quality, with no grafting skill and no equipment, and the cells end up concentrated in a known, accessible place where they can be counted, cut out and distributed rather than scattered through the brood nest. The honest caveat is that colonies given a free choice already tend to select young larvae, so notching helps most when you cannot otherwise verify age and when you want cells somewhere predictable.

On **emergency queens**, both dogmatic answers are wrong. Colonies given a genuine choice start most emergency cells on eggs and the youngest larvae and cull many of them, and the surviving queens are generally acceptable – work by Hatch, Tarpy and Fletcher supports this. The risk arises when there are no young larvae to choose from: a colony made queenless when its larvae are all three or four days old rears queens from those larvae because it has no alternative, and those queens are genuinely inferior. Genetically they are the same bees; developmentally they are not. So verify that larvae under about a day old were present when the colony was made queenless, use notching to direct the choice, or bypass the problem with a ripe cell or mated queen.

3.9 Cell Builders, Finishers and the Cloake Board

A **starter** is a colony made strongly queenless and ideally broodless, packed with young nurse-age bees. The absence of queen mandibular pheromone and of open brood releases the queen-rearing impulse, and the excess of nurses with developed hypopharyngeal glands supplies the jelly; acceptance in a good starter approaches ninety percent. The classic form is a **swarm box**: a closed, screened box of shaken young bees with pollen, honey and water, held cool and dark for a few hours before grafts go in.

But a swarm box cannot carry cells through the full larval period. It is confined, has nothing coming in, holds temperature less steadily than a full brood nest, and its nurses age out. What queen larvae need for the next four days is heavy sustained feeding at a stable 93 to 95 degrees F. A **finisher** supplies that: a strong queenright colony with the queen confined below an excluder and the cell bars above among

open brood and pollen. Queenright colonies feed cells better because they are not simultaneously running down. Hence **start queenless, finish queenright**.

A **Cloake board** does both in one hive. It is a split board with a removable slide, fitted with a queen excluder and an upper entrance, placed between two brood boxes with the queen below. Insert the slide **a day before grafting**: the upper box is now functionally queenless but keeps its foragers through its own entrance. **Graft** and place the bar above. **Remove the slide about twenty-four hours after grafting**: queen pheromone flows up through the excluder and the upper box becomes a queenright finisher. No bees are moved, the colony is never divided, and the same equipment turns out a round of cells every ten days or so.

Whatever the system, a builder must be **fed**: in the southeastern summer dearth, a builder without syrup and a protein source underfeeds cells no matter how many bees it holds. It also needs the same mite control as a production colony, since a builder carrying heavy Varroa produces queens compromised before you ever see them.

3.10 Mating Nuclei and Queen Banks

A mating nucleus should be **small enough to be economical of bees and equipment but populous enough to hold brood-nest temperature, feed and warm the emerging virgin, and defend itself.** Too large and you spend resources you could be using in production, and the unit builds up and swarms or supersedes before you harvest the queen. Too small and it cannot thermoregulate, cannot repel robbers, and is overwhelmed.

Stock it with **young bees and emerging brood**, not foragers: foragers shaken in near home simply fly back, while young bees have not oriented and stay. A serviceable unit has a frame of emerging brood, a frame of honey and pollen, bees enough to cover the comb solidly, and either a few days confined somewhere cool and dark or a location far enough away to prevent drift. Formats run from five-frame nucs through divided queen castles to purpose-built mini-mating nucs; smaller is more economical per queen and less forgiving of neglect.

The southeastern hazards are specific. **Robbing during dearth** makes a two-frame nuc in August a target: reduce entrances to a single bee-space, use robbing screens, and do not feed openly in the yard. **Small hive beetle** overwhelms small units faster than anything else here, because a nuc lacks the adults to patrol and corral them; keep bees covering every frame using follower boards rather than empty space, run beetle traps, and keep nucs off damp shaded ground. **Heat** demands afternoon shade, ventilation and water. And **neglect** kills: a nuc can be lost between weekly visits, so mating yards need more attention than production yards, not less.

The turnaround is predictable. A ripe cell goes in on day 10 after grafting, the virgin emerges within a day or two, matures five to six days, mates over the following days if weather permits, and lays by roughly two weeks after the cell went in. Allow three weeks from cell to a laying queen you would sell.

A **queen bank** holds caged mated queens until needed. It requires an unusual structure for a physiological reason: a caged queen is not laying and cannot be fed in the ordinary way, so each must be fed by attendant workers through the cage screen. That demands a very heavy population of young

nurse-age bees with functional food glands – far more than a colony normally devotes to one queen – usually a bank frame of cages above a queen excluder over a strong colony, with continuous syrup, a protein source, good ventilation and stable temperature. Two limitations: banks fail through **nurse-bee depletion** as the young bees age out, so fresh bees and emerging brood must be rotated in; and **prolonged banking carries real costs**, since survival can be poor and banked queens may start more slowly after introduction, even though queens that survive show little loss of sperm count or viability, making a bank a holding measure of days to a few weeks, not a storage strategy. In this region add heat and small hive beetle.

3.11 Introduction and Acceptance

A colony recognizes its own members chemically, and a queen released directly is usually balled and killed. The candy plug works because it takes a day or two to chew through, and during that interval **the colony acquires the queen's pheromonal signature through contact and food exchange across the screen**, so that at release the bees treat her as their own. Note what the mechanism is not: the candy is not the colony's food supply, and a well-provisioned colony is not thereby less motivated to release her; the delay is not for her benefit, since she is fully mature when shipped.

The failure modes follow directly. **The colony is not actually queenless** – an unnoticed virgin, a missed laying queen or a drawn queen cell defeats the introduction. **Queen cells remain or are started afterward**: a queenless colony detects the loss within hours and has emergency cells visible within a day or two, so destroy cells at introduction *and again about a week later*, since cells started before she was accepted will otherwise mature and produce a virgin who kills her. **Repeated disturbance** disrupts the process, so introduce, close up and leave it a week. **Dearth and robbing pressure** make acceptance measurably poorer in a stressed, defensive colony – the normal southeastern late-summer condition – which argues for light syrup at introduction and reduced entrances. **Laying workers** and a **forager-heavy age structure** both lower acceptance. Alternatives include the **push-in cage**, pressed into comb over emerging brood and stores so the queen lays immediately while bees emerging inside accept her at once, and direct release with heavy smoke or scented syrup – quick, occasionally effective, and reliably expensive when it is not.

A **test frame** of eggs and young larvae answers the queenlessness question in three to four days: a queenless colony starts emergency cells on it, a queenright one does not. That same speed sets the timeline for a walk-away split. Cells are started within a day; a queen emerges roughly twelve to sixteen days after the split depending on the larva selected; she matures five to six days, mates over the following days if weather permits, and lays. **Expect eggs three to four weeks after the split.** What can go wrong: the bees select an older larva and produce an undersized queen; the virgin is lost on a mating flight to a bird or weather; cold wet weather produces a drone layer; the split is too weak to keep cells warm or fend off robbers and beetles; or the anxious beekeeper opens the colony repeatedly during the mating period. The alternative – a purchased mated queen or a ripe cell – shortens the broodless interval by two to three weeks and gives known maternal genetics, at the cost of price and acceptance risk.

3.12 Marking, Clipping and Judging a Queen by Her Colony

The international marking code runs on a five-year cycle keyed to the last digit of the year: **white** for 1 or 6, **yellow** for 2 or 7, **red** for 3 or 8, **green** for 4 or 9, **blue** for 5 or 0. The mnemonic is **"Will You Raise Good Bees."** A queen introduced in 2026 is white.

Marking earns its keep for three reasons beyond findability: it **records the year of introduction**, the only reliable basis for an age-based requeening schedule; it **makes supersedure obvious**, since an unmarked queen where you marked one last spring means the colony replaced her without telling you; and it **protects a valued queen from accidental removal** during splitting or requeening. **Clipping** – removing about half of one forewing – is narrower. It does not prevent swarming; the colony still decides and still builds cells. It prevents a clipped queen leaving with a prime swarm, so the swarm usually settles near the hive and returns, buying time to intervene. Against that: a clipped queen that does leave is often lost in the grass, clipping makes supersedure somewhat more likely, and it removes wing wear as an age cue. Handling of any kind raises the chance of a supersedure attempt in the following weeks.

The laboratory measures of quality are **live weight** at emergence or onset of lay, **ovariole number**, **spermatheca diameter**, and the **number and viability of stored spermatozoa**. Benchmarks commonly cited: roughly 190 milligrams or more at emergence, 300 or more ovarioles in total, a spermatheca above about one millimeter, and stored sperm above roughly three to four million with high viability. Surveys of commercial queens have found mean weights in the mid-180-milligram range and mean stored sperm near four million with very wide ranges – so a substantial minority of purchased queens are below benchmark on arrival.

None of that is measurable in the field. The field proxy is **brood pattern quality and extent over several weeks, plus colony build-up and the absence of repeated supersedure attempts.** Use it carefully: a spotty pattern can be caused by Varroa and its viruses, chilled brood at the margins, brood disease, sex-locus inbreeding producing diploid drone larvae that nurses remove, or a pollen-bound nest where a sound queen has nowhere to lay. Exclude those before condemning her, and do not judge by appearance – size, color and demeanor are weak predictors, because a queen's merit is expressed by her workers, not her body.

To compare two queen sources fairly: **replicate** with ten or more queens per source, since single-colony comparisons are dominated by chance; **equalize** colonies for population, brood, stores and equipment; **distribute** both sources across every apiary and every position, because putting one source in one yard confounds source with site, forage and microclimate beyond any later rescue; **manage identically**; and **measure defined things** – acceptance rate, time to laying, brood pattern scored the same way each time, build-up, temperament, mite growth, honey production, overwintering survival – scored blind to source where possible. Replication across locations and seasons is what turns an impression into evidence.

3.13 The Southeastern Mating Calendar and Drone Lead Time

Plan backward from the day virgins will fly: subtract five to six days of maturation and eleven to twelve days from graft to emergence, and you have your graft date. Then plan the drones separately, because

their calendar is far longer. **Start drone mother colonies about six weeks before the first virgins fly**, and give them drone comb, feed and mite control – Varroa reproduce preferentially in drone brood, and an untreated drone mother produces drones with compromised sperm. At the other end of the season, colonies evict drones as resources tighten, and the practical indicator that your window is closing is the absence of drones on the comb and at the entrance.

This is where the region has a genuine edge. In the lower coastal plain drone brood commonly appears in late winter and drones fly well before most of the country has broken cluster; at the other end, coastal plain and warmer piedmont colonies often carry drones into October and beyond where an autumn flow keeps resources coming in. Against a northern drone window of perhaps twelve weeks, a southeastern beekeeper may have five months of usable mating weather in the coastal plain, less in the southern Appalachian mountains where the season is compressed and shifts later with elevation. **Early spring rearing is therefore possible here**, which is why so much of the country's queen production is southeastern; the constraint is not warmth but drone maturity, since there are days warm enough for a virgin to fly before there are mature drones to meet.

Late-summer and early-autumn requeening is the stronger argument. A young queen going into autumn holds a higher laying rate and stronger pheromone output, supporting a good population of long-lived, vitellogenin-rich winter bees, and she takes the colony into spring with less swarming pressure and less risk of mid-season supersedure. The requeening interval also produces a **brood break** that can be combined deliberately with mite treatment: with no capped brood to hide in, mites are exposed, and treatments that do not penetrate cappings – oxalic acid in particular – become far more effective. A late-summer requeening paired with a broodless-window oxalic treatment is among the highest-value management available in this region.

State the drawbacks whenever you state the advantages. Acceptance is poorer during the late-summer dearth with high robbing pressure, so feeding and reduced entrances are needed. Good queens are harder to obtain late in the season. Late-season drones may be fewer and poorer, making locally mated autumn queens a greater gamble than purchased ones. And requeening always carries acceptance risk and cost: a demonstrably excellent queen may be worth keeping, and "requeen everything annually" is a policy, not a judgment.

3.14 Numbers to Know Cold

Figure	Value	Why it is that value
Queen, egg to emergence	about 16 days	Richer diet drives faster growth, earlier pupation
Worker / drone, egg to emergence	21 / 24 days	Longer feeding and pupal periods
Queen cell capped	day 8 from the egg	End of about 5.5 days of larval feeding
Ideal grafting age	under 24 hours	Queen-type feeding before the pathways diverge sets ovariole number and weight

Figure	Value	Why it is that value
Graft to capping / to emergence	4-5 days / 11-12 days	The grafted larva is already 4 days from the egg
Cell handling day	day 10 after grafting	Past the shock-sensitive stage, before first emergence
Incubator conditions	93-95 degrees F	Brood-nest temperature; a hot vehicle kills pupae in minutes
Virgin sexual maturity	5-6 days after emergence	Reproductive tract matures before flight
Drone sexual maturity	12-16 days after emergence	Sperm migration completes after emergence
Drone lead time	36-40 days from egg; plan 6 weeks	24 days to emergence plus 12-16 to maturity
Unmated virgin becomes a drone layer	about 3 weeks after emergence	Laying starts whether or not the spermatheca filled
Drones mated per queen	About 12 on average (wide range)	Usually 1-3 flights over 1 to several days
Sperm per drone ejaculate	about 10 million	A drone's lifetime production, delivered once
Sperm entering the oviducts	50-100+ million	Sum across matings; most expelled within a day or two
Sperm retained in the spermatheca	about 5-7 million	Only a fraction migrates in; the lifetime supply
Spermatheca diameter benchmark	above about 1 mm	Correlates with storage capacity and mating success
Queen weight benchmark	190 mg or more at emergence	Commercial means run mid-180s, so many fall short
Ovarioles	300+ in a queen; 2-12 in a worker	Built by larval feeding; never restored once lost
Stored sperm benchmark	above 3-4 million, high viability	Commercial mean about 4 million, range 0.2-9 million
Thermal safe zone	59-100 degrees F for 2-4 hour exposures	Outside it, viability falls with no outward sign
Viability loss tied to failure	about 11.5 percent	Field threshold linking sperm damage to failure
Emergency cells started	within hours; visible in 1-2 days	Loss of queen pheromone is detected very quickly
Test frame verdict / cell recheck	3-4 days / about 7 days	Cells visible by then; pre-acceptance cells mature by then
Walk-away split to first eggs	3-4 weeks	12-16 days to emergence, 5-6 to mature, then mating

Figure	Value	Why it is that value
Cloake slide	in 1 day before graft, out about 24 hours after	Queenless for starting, queenright for finishing
Marking colors	White 1/6, Yellow 2/7, Red 3/8, Green 4/9, Blue 5/0	“Will You Raise Good Bees”

3.15 Common Misconceptions

Misconception: An isolated yard means my queens mate with my own drones. **Correction:** Congregation areas draw drones from every colony within several kilometers, including feral ones, and drones from many colonies, often kilometers away, converge on the same sites. Saturation shifts the odds of paternity; it never determines them, which is why purchased selected genetics do not persist in open-mated daughters.

Misconception: A queen mates once, on one flight, with one drone. **Correction:** She mates in flight with about twelve drones on average, usually across one to three mating flights over one to several days, and each drone dies in the act. That polyandry gives a colony its patrilines and the thermoregulatory stability, task diversity and disease resistance that come with them.

Misconception: A queen can mate again later if she runs low on sperm. **Correction:** Mating is confined to a narrow window in early adult life. The spermatheca is filled once and never topped up. A queen whose stored sperm is depleted or dead becomes a drone layer, and no feeding or management restores the supply.

Misconception: Larvae up to three or four days old graft fine, since they get royal jelly once they are in the cup. **Correction:** The diet *before* the transfer is what matters. Ovariole number, spermatheca size and adult weight are set by the duration of queen-type feeding before the pathways diverge, and ovarioles lost to programmed cell death in a worker-fed larva are not restored. Older grafts give measurably inferior queens, superseded more often.

Misconception: Queens damaged by heat or cold in shipping can be spotted and culled on arrival. **Correction:** There is no outward sign. A thermally damaged queen looks normal, is accepted normally, and lays well briefly before producing patchy or drone-heavy brood or being superseded. Because you cannot screen for it, the controls are preventive: prompt collection, moderate holding temperature out of sun, prompt introduction.

Misconception: The candy plug works because the bees must chew through to reach food. **Correction:** It works because the interval lets the colony acquire the queen’s pheromonal signature through contact and food exchange across the screen. A colony with abundant stores is not less likely to release her. The real mechanism tells you which errors matter: a colony that is not truly queenless, an unnoticed cell or virgin, and repeated disturbance.

Misconception: A colony rearing its own emergency queen always produces a poor queen. **Correction:** The verdict is conditional. Colonies given a genuine choice start most emergency cells on eggs and the youngest larvae and cull many of them, and the surviving queens are generally acceptable. The real risk

is a colony made queenless when only older larvae are available. Verify that larvae under about a day old were present, use notching to direct the choice, or supply a ripe cell or mated queen.

Misconception: Drone mothers can be set up alongside the graft, since drones mature quickly. **Correction:** That applies the queen's timetable to the wrong caste. A drone needs about 24 days to emerge and a further 12-16 days to mature – roughly six weeks – before you add time to fill drone comb. Using the queen's figures leaves virgins flying into an area stocked with somebody else's drones.

Misconception: Scattered drone brood in worker cells means laying workers. **Correction:** Look at egg placement. A failing queen lays single eggs centered on the cell floor; they are simply unfertilized, so they become drones with domed cappings in worker cells. Laying workers place multiple eggs erratically, often on the cell walls, because their abdomens cannot reach the base. The remedies are opposite: remove a drone-laying queen and requeen, but combine a laying-worker colony with a strong queenright colony, preferably by shaking its bees out in front of it.

Misconception: A laying-worker colony can be fixed by buying it a queen. **Correction:** Workers with activated ovaries behave in some respects as though the colony were queenright, so the colony typically balls and kills an introduced queen. Combining with a strong queenright colony is the reliable remedy, and shaking the laying-worker bees out in front of it is more reliable than a straight newspaper combine; repeated frames of open brood also suppress ovary development. Often the unit is not worth rescuing individually.

Misconception: A spotty brood pattern means a bad queen. **Correction:** It means something is wrong with the brood, which may or may not be her. Varroa and its viruses, chilled brood, brood disease, sex-locus inbreeding producing diploid drone larvae that nurses remove, and a pollen-bound nest all produce poor patterns with a sound queen present. Judge her over several weeks, not one inspection.

Misconception: Clipping the queen prevents swarming. **Correction:** It prevents nothing about the colony's decision; cells are still built and the attempt still made. It stops the queen flying with the prime swarm, so the swarm usually settles near the hive and returns, buying time to intervene. Against that, a clipped queen that does leave is often lost in the grass, and clipping slightly raises the chance of supersedure.

Misconception: A queen bank is a way to store queens through a slow patch. **Correction:** It is a short-term holding measure. Caged queens are fed by attendants through the screen, requiring a very heavy population of young nurse bees that must be rotated in as they age out, and prolonged banking carries real costs, with poorer survival and a slower start after introduction. In this region add heat and small hive beetle.

Misconception: Miticide residues in wax poison the queen directly. **Correction:** The evidence is more nuanced. Adult queens exposed topically to wax-typical pesticides at many times realistic levels showed no effect on mass or sperm viability, while contaminated pollen fed to rearing colonies did reduce viable queen production and sperm viability. The pathway appears to run through the nurse bees and the jelly they make, so the control is comb rotation and clean wax and pollen.

Misconception: *Nosema* is a worker problem; a queen from an infected colony is safe to move. **Correction:** It can infect the queen's midgut. Infected queens show altered physiology, including shifts in vitellogenin and mandibular pheromone levels, and infection has been linked to supersedure, with no external sign, so microscopy is required. Operationally, a caged queen is fed by attendants through the screen, so escort bees for cages and banks should come from colonies with low spore counts.

3.16 Self-Check Questions

- Explain the mechanism by which a fertilized egg becomes a queen rather than a worker, naming at least two lines of evidence, and say where the science is contested.
- A queen emerges in 16 days and a worker in 21. Explain why the queen is faster, not slower, given that she is the larger adult.
- You graft on a Monday. State when the cells are capped, when you move them, and when they emerge, and justify the moving day with two independent reasons.
- Distinguish the number of drones a queen mates with from her effective paternity, and explain why the second predicts colony performance.
- A program needs the first virgins flying on 1 May. Give the date drone mothers should be laying drone eggs, and show the arithmetic.
- Describe the sequence from a virgin's emergence to her first eggs with approximate day numbers, and explain what a fortnight of cold wet weather in the middle of it does.
- A colony has single eggs centered in worker cells and about half its sealed brood is domed drone brood in worker-sized cells. Diagnose it, explain the mechanism, and distinguish it from the condition it is confused with.
- Explain why cells are started queenless but finished queenright, and describe how a Cloake board does both in one hive, with timing.
- A queen arrives after two days in a hot postal facility and looks perfect. Explain what may have happened, why you cannot detect it, and what you should do.
- Give the four laboratory measures of queen quality with benchmark values, name the field proxy, and list four things that spoil that proxy with a sound queen present.
- You are comparing two queen sources. Describe your design and explain why distributing both sources across all yards matters more than any other single choice.
- State the case for late-summer or early-autumn requeening in the southeastern US, including the mite-management synergy, and give two genuine drawbacks.
- Explain what a queen bank is, why it needs an unusual colony structure, and give two limitations.
- A split made on 1 April is left to rear its own queen. Give the expected date range for first eggs and four things that could prevent it.

3.17 Self-Check Answers

- Caste is set by the feeding regime over roughly the first three days of larval life. Queen larvae are fed continuously and to excess on a jelly far richer in mandibular secretion and much higher in sugar; worker larvae get a diluted jelly supplemented with pollen and honey. Heavy feeding drives nutrient-sensing pathways that raise juvenile hormone, which suppresses the programmed cell death destroying most worker ovarioles. Diet-driven DNA methylation marks the two trajectories – silencing *Dnmt3* produces queen-like adults on a worker diet. Worker jelly also carries phytochemicals such as p-coumaric acid that alter caste-associated gene expression. The contested claim is that a single protein, "royalactin," is the queen-inducing factor; a later study failed to reproduce it.

- The richer, more abundant diet drives a much higher growth rate and an earlier hormonal cascade to pupation, so she reaches final larval mass sooner, is capped on about day 8 rather than day 9, and has a compressed pupal period. Size at emergence is a product of feeding intensity, not time spent developing: she is larger because she was fed far more per day, not for longer. The consequences are practical – a queenless colony can have a replacement emerging in eleven or twelve days, and the first virgin out of a bank of cells destroys her sisters before your next visit.

- Capped Friday or Saturday, four to five days after grafting. Moved the following Thursday, day 10. Emerging Friday or Saturday of that week, eleven to twelve days after grafting. Day 10 is chosen for two independent reasons. Earlier in development the queen pupa is vulnerable to chilling and to mechanical shock, and damage from either produces a deformed or dead queen with no warning until she fails to emerge. And the first queen to emerge tears down every remaining cell, so cells must be separated before any can emerge.

- The number of matings is the count of drones that successfully inseminated her. Effective paternity is a genetic estimate of how many fathers are actually represented among her workers, obtained by genotyping a worker sample and correcting for sampling error. The two differ because drones contribute unequally to the sperm stored and used, so a queen that mated with twenty may have an effective paternity well below that if a few drones dominate. Effective paternity is the operative figure because colony-level benefits – graded thermoregulation, task specialization, disease resistance, productivity – depend on the genetic variance actually present among the workers.

- A drone needs about 24 days from egg to emergence plus 12 to 16 days to sexual maturity: 36 to 40 days, call it six weeks. Six weeks before 1 May is about 20 March. Add time for the drone mothers to be given or to draw drone comb and for the queen to fill it, so realistically have them set up and laying in drone comb by mid-March. Starting drone production at the first graft would leave drones roughly three weeks short of maturity when the virgins fly – precisely long enough to miss the window.

- She emerges on day 0, hardens, and matures about five to six days. From roughly day 6 she takes orientation flights and then mating flights on warm calm afternoons, mating with about a dozen drones on average across one to three flights over one to several days. She begins laying within a day or two of her last flight, so eggs by roughly day 10 to 14. A fortnight of cold wet weather removes her flight opportunity entirely, since drones will not fly in it either. If still unmated at about three weeks she typically begins laying unfertilized eggs, and the colony has a drone layer from the start.

- A failing or partially failing queen, often called a drone layer. Her behavior is normal – single eggs centered in the cell – because she still measures cells correctly with her forelegs. What has failed is fertilization: stored sperm is depleted or its viability reduced, so a proportion of eggs go unfertilized and develop as drones, and drone larvae in worker-sized cells get raised domed cappings. Causes include advanced age, poor mating and thermal damage in shipping. Laying workers instead place multiple eggs erratically on cell walls rather than singly and centered. The remedies differ: remove this queen and requeen; a laying-worker colony must be combined.

- A queenless, broodless unit packed with young bees accepts grafts at a much higher rate, because the absence of queen mandibular pheromone and of open brood releases the queen-rearing impulse. But such a unit, particularly a confined swarm box, cannot sustain optimal feeding, temperature and provisioning for the full larval period; a strong queenright colony above an excluder does that better. A Cloake board – a split board with a removable slide, a queen excluder and an upper entrance – does both. The slide goes in a day before grafting, making the upper box functionally queenless for starting, and comes out about 24 hours after grafting, restoring queenright conditions for finishing.

- Stored sperm may have been killed by heat. The established safe zone is roughly 59 to 100 degrees F for two-to-four-hour exposures, and tracked shipments have reached both extremes. There is no outward sign: she will look normal, be accepted, and lay well for weeks before producing patchy or drone-heavy brood or being superseded. Since I cannot screen for it, I would introduce her normally but mark her, record the shipping incident, and deliberately inspect her brood pattern at four and eight weeks with replacement stock on hand. The controls going forward are preventive: prompt collection, moderate holding temperature, no parked vehicles.

- Live weight at emergence or onset of lay, roughly 190 mg or more; ovariole number, 300 or more in total; spermatheca diameter, above about one millimeter; and stored sperm count and viability, above roughly three to four million with high viability. The field proxy is brood pattern quality and extent over several weeks, plus build-up and the absence of repeated supersedure attempts. Four things that spoil it with a sound queen: Varroa and the viruses it vectors killing brood; chilled brood at the edges of an undersized cluster; brood disease such as European foulbrood or chalkbrood; and a pollen- or honey-bound nest leaving her nowhere to lay.

- Ten or more queens per source, introduced into colonies equalized for population, brood, stores and equipment, managed identically, and scored on defined measures – acceptance, time to laying, brood pattern, build-up, temperament, mite growth, honey yield, overwinter survival – blind to source where possible. Distributing both sources across every yard and position matters most because site effects are large and systematic: forage, microclimate, pest pressure and even position in a row shift performance substantially. If one source sits in one yard, source is perfectly confounded with site and no later analysis can separate them.

- A young queen going into autumn holds a higher laying rate and stronger pheromone output, supporting a good population of long-lived winter bees, and carries the colony into spring with less swarming pressure and less risk of mid-season supersedure. The requeening interval creates a brood break, and a broodless or nearly broodless window sharply raises the efficacy of treatments that do not penetrate cappings, so oxalic acid timed to that gap is far more effective than the same treatment over capped brood. Drawbacks: acceptance is poorer during the late-

summer dearth with high robbing pressure, and good queens are harder to obtain late in the season.

- A queen bank is a colony used to hold caged mated queens until needed. It needs an unusual structure because caged queens are not laying and cannot be fed in the ordinary way; each must be fed by attendant workers through the cage screen, which demands a very heavy population of young nurse-age bees with functional food glands, usually held above a queen excluder over a strong colony with continuous syrup, a protein source, good ventilation and stable temperature. Limitations: banks fail through nurse-bee depletion, so fresh young bees must be rotated in; and prolonged banking carries real costs, with poorer queen survival and a slower start after introduction. Regionally, add heat and small hive beetle.

- Emergency cells start within a day. A queen emerges roughly twelve to sixteen days after the split – about 13 to 17 April – matures five to six days, mates over the following days if weather permits, and lays. Expect first eggs roughly three to four weeks after the split: about 22 to 29 April. Things that can prevent it: the bees select an older larva and produce an undersized queen that fails or is superseded; the virgin is lost on a mating flight to a bird or weather; cold wet weather during the mating window produces a drone layer; the split is too weak to keep cells warm or defend itself against robbing and beetles; or repeated inspection disrupts her.

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Chapter 4. Swarming, Supersedure & Absconding

Covers exam questions Q72-Q85.

4.1 Orientation

Three different events can empty or halve a hive, and beekeepers routinely mistake one for another. A colony that swarms has reproduced: it divided, sent out a mated queen with most of its workforce, and left behind brood, stores and the means to make a new queen. A colony that supersedes has replaced a failing queen in place, usually without losing a bee. A colony that absconds has fled, the whole adult population walking out and abandoning brood and honey because conditions inside became worse than the risk of leaving. The exam exploits this confusion, because the three look similar on an inspection sheet and the correct response to each is completely different.

The first organizing idea is that swarming is a response to prosperity, not hardship. It requires a large population, good forage, a surplus of young bees and mature drones. Dearth suppresses reproductive swarming and instead raises the risk of the other two events, so any explanation of swarming built on scarcity is wrong on its face.

The second is that the swarming impulse is a physiological state of the colony, not a pile of wax on the bottom bars. Queen cells are the symptom; remove the symptom and leave the condition and the colony rebuilds within days. Every manipulation that works - Demaree, artificial swarm, split, checkerboarding, timely supering - changes the condition, by restoring laying space, raising each bee's share of queen pheromone, or removing the surplus population the impulse requires.

The third is a calendar. Here the build-up begins with red maple and willow in the coldest part of the year, and the swarm season opens in the coastal plain in late February, in the piedmont in March, in the southern Appalachian mountains in April. A beekeeper working to a northern calendar that begins weekly inspections in late April will find his swarms already gone.

4.2 What Drives the Swarming Impulse

The queen produces queen mandibular pheromone (QMP, whose principal component is 9-oxo-2-decenoic acid) and a tarsal or footprint pheromone she deposits as she walks the comb. Workers acquire both by contact and spread them by trophallaxis and grooming. That circulating signal is the colony's evidence of a good queen, and among other things it inhibits the provisioning of queen cups.

Her output is roughly fixed; the number of bees sharing it is not, so a colony growing from 20,000 to 40,000 bees halves the per-bee share. Congestion compounds this mechanically: when every comb is packed with bees and the cells around the brood nest are backfilled with nectar, the queen cannot circulate freely, so she lays less, deposits footprint pheromone over less comb, and contacts fewer workers. Dilution and restriction act together, and once the signal falls below threshold in enough of the colony, workers charge the cups they already maintain.

Congestion alone is not sufficient. The co-requisites, which the examiner expects named together, are a surplus of nurse bees under about ten days old - swarm cells are lavishly provisioned with royal jelly and

a swarm's first job is secreting wax, both young-bee tasks, which is why departing bees skew young; ample incoming forage, which funds the wax and brood and drives the backfilling that crowds the queen; and a mature drone population, since the virgin left behind must mate. Drone brood and flying drones appear weeks before the first charged cup and are the most useful early warning available.

Queen age and genetics modulate the rest. Second-season queens swarm more readily, because pheromone output declines with age and an older queen fills the brood nest more slowly, but age acts on top of the other conditions rather than instead of them: a second-year queen with ample room, in a dearth, will not swarm. Stock matters greatly here, since African-derived genetics carry a markedly higher swarming and absconding tendency, and any colony of unknown maternal line should be assumed swarmier than purchased stock. Day length is not a trigger; photoperiod acts indirectly through forage phenology, and two hives on one stand routinely differ by a month.

4.3 The Swarm Sequence and Its Arithmetic

A normal colony keeps a dozen or more empty queen cups standing all season, and they mean nothing. The sequence begins when a cup is *charged* - an egg laid in it or a very young larva moved into it, the walls drawn and provisioned - and from there the timing is fixed by queen development.

Event	Day from the egg	What you see
Egg in charged cup	0	Extended cup, egg standing in it
Cell sealed	8	Capped peanut cell; **prime swarm departs at or just after this**
Virgin emerges	16	Hinged round cap at the cell tip
Mating flights	about 20-24	Warm afternoons
First eggs from the new queen	about 24-30	Two to three weeks after the swarm left

The eight-day capping interval is the entire reason for the seven-day inspection cadence. A cup charged the day after you close the hive is still open when you return on day seven; at ten days it can be charged, capped, and the colony gone before your next visit.

In the days before departure workers stop feeding the queen and repeatedly shake her so she cannot settle and lay. She loses roughly a quarter of her body weight, her ovaries regress, and she becomes capable of sustained flight. The shutdown is reversible, which is why a hived swarm's queen resumes laying within days once the bees feed her again.

The prime swarm leaves on a warm day with the old mated queen and over half the adults, each carrying about three days of honey. It bivouacs nearby while several hundred scouts search for cavities and advertise them by waggle dance on the cluster surface, dance vigour scaling with site quality. When roughly ten to twenty scouts (about fifteen is the figure usually quoted) have accumulated at one site a quorum is reached, piping begins, the cluster warms and the swarm flies - after anything from an hour to three days.

4.3.1 Afterswarms

Eight days after the prime swarm the first virgin emerges, and a colony still holding population and sealed cells may cast again. Afterswarms differ from the prime swarm in four ways: they carry one or more *virgin* queens rather than the old mated queen; they are smaller, often much smaller; they issue in succession at roughly one- to three-day intervals as each virgin is released; and they can reduce the parent below the strength it needs to defend itself, rear brood and mate a queen. An emerged virgin toots and virgins still held in their cells answer with a muffled quacking, so a colony making both sounds is holding queens back and is likely to cast.

Once the prime swarm has gone the objective changes from prevention to limiting casts, and the two correct actions are to reduce the cells to a single good one, or to destroy all cells and introduce a mated queen. A colony that casts three times in early spring will be a nucleus by June and will meet the summer dearth and beetle pressure with too few bees to patrol its own comb.

4.4 Reading Queen Cells: The Convention and Its Limits

	Swarm cells	Supersedure cells	Emergency cells
Number	Many; ten or more	Few; one to three	Several, often clustered
Position	Bottom bars, lower margins	Comb face	Comb face, where young larvae were
Origin	Purpose-built cup	Purpose-built cup	Converted worker cell, turned down
Queen	Present and laying	Present but failing	Absent; lost abruptly
Colony	Large, congested, backfilled	Ordinary strength	Any
Brood pattern	Full until backfilling starts	Spotty, drone brood in worker cells	Normal, then ageing out
Outcome	Colony divides and departs	Queen replaced in place	Colony requeens itself or fails

Position alone fails for three reasons. Supersedure and emergency cells both occupy the comb face, so face position does not separate them at all; a severely congested colony builds swarm cells on the face once the bottom bars are full; and a colony can run two processes at once, having started swarm cells and then lost or superseded its queen, leaving cells of two ages in two positions.

What resolves the reading is context. Is the queen present, and is she the one you expected, marked and clipped as you left her? Are there eggs - eggs beside sealed queen cells mean she was laying within three days, which rules out abrupt loss. How congested is the colony, is the brood nest backfilled, are drones flying, and what is the brood pattern, since a failing queen gives a spotty pattern with scattered drone brood in worker cells that supports supersedure even when the cells sit low. One cell on a comb face in October, in a colony of moderate strength with a poor pattern, is a supersedure whatever the

book says about position; ten cells on the bottom bars of a boiling colony during the March maple flow are swarm cells whatever else is true.

Two cautions about cells themselves. An emergency cell raised from a larva already several days old yields an undersized queen, so keep the cells built from the youngest larvae and cull the rest. And a cell torn open *from the side* was destroyed by a rival queen or by workers, while a cell opened by a *hinged cap at the tip* released its queen normally, which tells you whether a virgin is loose in the box.

4.4.1 Supersedure biology

Supersedure is queen replacement without division. The colony detects failing output - reduced pheromone, reduced laying, a deteriorating pattern, injury - and raises one to three cells on the comb face while the queen is still present and often still laying. The old queen is then usually balled or simply disappears, though mother and daughter laying side by side for weeks is well documented and normal. Triggers include age, injury in handling, poor mating and sperm exhaustion, sublethal pesticide or miticide exposure, and Nosema or virus load. It is usually the colony being right, at a cost of about a month's brood break, and the only real risk is mating: a supersedure in late autumn, or in a cold wet stretch when drones are scarce, can leave a drone-layer or nothing, and that is when you destroy the cells and introduce a mated queen. Three supersedures in one season point past the queens to something acting on all of them - contaminated comb, virus load, genetic incompatibility - and the answer is to replace comb and maternal line together.

4.5 Swarm Control: What Works and Why

4.5.1 Why cutting cells alone fails

Destroying every cell and changing nothing else is the commonest error in the craft, and it fails for four reasons. The congestion that started the cells remains, so the colony recharges cups within a day or two and can cap them eight days later. You will miss one - on the far face of a comb you did not turn, behind burr comb, at the bottom bar of a frame set in the grass - and one overlooked sealed cell defeats the exercise. Worst, if the colony has already swarmed and you have not confirmed the queen is present and laying, destroying every cell removes its only route to a queen, and it will develop laying workers and die. Cell destruction is legitimate *inside* a manipulation that removes the cause, and fails on its own.

Manipulation	What it does	Which driver it removes	Cost
Supering ahead	Adds storage space above	Reduces backfilling; relieves crowding	Beetle exposure if overdone
Drawn comb into the brood nest	Gives the queen cells to lay in today	Restores laying space and pheromone circulation	Needs drawn comb
Reversing	Puts empty comb above the cluster	Restores upward laying space	Can split a brood nest in cold weather
Checkerboarding	Alternates honey and empty comb above the brood nest	Breaks the overhead reserve the colony reads as a cue	Must be early; needs comb

Manipulation	What it does	Which driver it removes	Cost
Demaree	Queen below on open brood, excluder, sealed brood above	Congestion and laying space, keeping one foraging force	Needs a follow-up cell inspection
Artificial swarm	Queen and flyers on the original site	Removes the surplus population	Two units; parent loses foragers
Split	Divides bees and brood	Removes the surplus outright	Sacrifices the crop
Cutting cells alone	Removes the symptom	Nothing	A week; queenless risk

4.5.2 Adding room, reversing, checkerboarding

Supering ahead of the bees means adding space before the colony needs it, so nectar goes upstairs instead of backfilling the brood nest, the queen keeps her laying room, and the population spreads over more comb, easing the crowding that restricts her movement and pheromone deposition. During a strong flow, being early costs almost nothing. The regional counterweight is small hive beetle: comb the bees cannot cover is comb beetles breed in, and a super of unattended comb over a mediocre colony is where slime-out begins. The practice is therefore conditional - super generously on strong colonies during a flow, conservatively on weak ones, and pull supers promptly when the flow ends. The same logic governs foundation, which a strong colony draws beautifully in a flow and leaves as one more undefended surface in a dearth.

Through late winter the cluster works upward, so brood often ends up in the top box with empty comb below; reversing returns the brood to the bottom and gives the queen room to expand upward, which she does more readily than downward. Do not reverse when the brood nest spans both boxes and a cold snap is possible, and note that the evidence that reversing *alone* prevents swarming is weak. Inserting drawn comb among the brood frames is the stronger version of the same idea.

Checkerboarding, developed by Walt Wright, alternates frames of capped honey with empty drawn comb in the one or two boxes immediately above the brood nest, before swarm preparation begins. The proposed mechanism is that the colony reads an unbroken band of capped honey overhead as the reserve that must be secured before reproduction is safe, so breaking its continuity keeps the colony expanding instead of committing. Timing is the whole trick - it must be done at the very start of the build-up, which here means late winter - and it needs drawn comb. The evidence base is field experience rather than controlled trial, and a candidate should say so.

4.5.3 Demaree

Leave the queen in the bottom box on one or two frames of open brood, filling the rest of the box with drawn comb or foundation. Put a queen excluder above her, normally with a honey super between. Move the great majority of the sealed brood, on its combs, into a box above the excluder, and destroy any cells present. The queen now has a full box of empty comb and few bees crowding her, so congestion is gone and laying space restored, while the brood above continues to emerge and those

young bees move down through the excluder. Nothing is lost, and over about three weeks the upper box empties of brood and becomes honey storage.

The failure mode is the follow-up. Brood above an excluder is queenless brood and starts emergency cells within a day or two, and they must be found and destroyed seven to nine days after the manipulation, before any can produce a virgin (cells raised on young larvae are capped within about five days and can emerge from about day ten), or you get a virgin above the excluder - unable to leave to mate, or mating and establishing a second laying queen in the stack.

Demaree is preferred over a split whenever the objective is a crop, and the reason is arithmetic. Surplus is what remains after a colony pays its own maintenance, and that cost does not halve when the colony is halved, so one very large colony sends a far greater proportion of its foraging into surplus than two medium ones. Demaree keeps the whole population as one foraging unit; a split divides the workforce and, made just before the main flow, normally forfeits the crop.

4.5.4 The artificial swarm, and splits

The Pagden artificial swarm reproduces the natural population split using forager fidelity to the site. Move the parent colony off its stand to a position nearby, and on the original site put a hive of drawn comb or foundation containing the single frame of brood that carries the queen, with every queen cell removed from it. Foragers navigating back to the old location pour in and join her, producing a unit with the mated queen, the entire flying force, one frame of brood and no queen cells - functionally a swarm in a box. The impulse is satisfied because the surplus population is gone from the parent and the queen has unlimited laying space.

Three requirements: find the queen and move her cell-free; reduce the parent's cells to one good cell or it will cast; and account for the parent's loss of all its foragers with stores and time while its young bees age into flying. The classic refinement is to move the parent again a week later, to the other side of the artificial swarm, bleeding a second cohort of newly orienting foragers into the queenright unit. The Snelgrove board works the same principle in one stack, using a division board with doors at several levels to redirect flyers repeatedly from the queenless upper unit into the queenright lower one, concentrating strength for the flow while the upper unit raises a queen.

A split removes the population surplus outright and is the most reliable method, and the one that costs the crop. It is the right answer when the objective is increase, when the beekeeper cannot commit to weekly inspections, when cell building is well advanced, or when the stock is defensive and requeening is wanted anyway. It is also the standard way to convert a swarm impulse into a deliberate brood break, which is where swarm control meets mite control.

4.6 Nest-Site Selection and Bait Hives

Scouts assess cavities against measurable criteria, which is why a well-built trap outcompetes a hollow oak. Seeley and Morse tested the preferences experimentally: a volume near 40 liters over 10 or 100; a small entrance of roughly 10 to 30 square centimeters (12.5 was chosen over 75 in direct comparison); the entrance low in the cavity rather than at the top, so comb is built downward above it; a height

around five meters over one; a southerly aspect; a hint of a preference for sites beyond about 300 meters from the parent nest; and the odour of old comb.

Each has a corollary. A ten-frame deep holds roughly 40 liters, which is why it is the standard bait hive. Reduce its entrance to a couple of square inches at the bottom, mount it as high as you can safely retrieve it, and face it south or southeast. Put one frame of old dark comb in it for the comb odour and a starting point, the rest foundation, and add a lure or a few drops of lemongrass oil, whose citral mimics components of Nasonov pheromone. Site it away from your own apiary. The regional error is the deployment date: traps must be out and baited before the season opens - February in the coastal plain, not April - and checked weekly, because a swarm that fills a trap with comb is a far harder transfer than one hived within days, and an unattended trap becomes a beetle and wax moth incubator.

4.7 Handling a Swarm of Unknown Origin

Hive it on foundation or clean comb of known history, not on your best dark brood comb. The bees carry whatever their parent colony had in their guts and on their bodies, but they do not carry their old comb, so clean wax keeps the inherited burden as small as possible.

Keep it away from the main apiary and watch it: temperament across several successive inspections rather than one good day, queen performance once she lays, and the first brood cycle for disease. A swarm carrying *Paenibacillus larvae* spores in its honey crop shows nothing until it has larvae to infect, two to three weeks out, and that first sealed brood - sunken, greasy, perforated cappings, a ropy test - is the reason for the quarantine.

Assess mites, since a swarm's load is reduced but not absent and one taken from a collapsing feral colony can be heavily infested. Treating before it has sealed brood is unusually effective, because every mite present is phoretic and an oxalic acid application reaches essentially the whole population. Then consider requeening with known stock: where African-derived bees occur the genetics of a feral swarm are genuinely unknown, and requeening replaces the maternal line at once and the whole workforce within about six weeks as the existing bees die off.

A frame of open brood is a real anchor against decamping, since bees will not readily abandon larvae they are feeding, but the claim that it carries no risk is flatly wrong and the exam builds a distractor on exactly that claim. The frame carries whatever the donor carries - American and European foulbrood, chalkbrood, viruses, Nosema, mites in the sealed cells - into a swarm that was starting comparatively clean, and swarm bees do not clean an infected comb before it affects them. Take the frame only from a colony whose health you have verified, or skip brood entirely and hold the queen for two or three days with an excluder at the entrance while feeding light syrup, since comb-drawing is itself an anchor.

4.8 Swarming and Varroa

A swarm starts with a low mite load for a structural reason. During active brood rearing most of the mite population is inside sealed cells, and only the phoretic fraction, something like a sixth to a quarter of the total, rides on adults. A swarm takes adults and leaves the brood, so it carries only that fraction and

mites per bee fall, and the brood break that follows compounds the effect because while the swarm draws comb the mites have nowhere to reproduce.

That tempts the argument that swarming is natural mite control, and the expected answer is that it fails on every practical axis. The parent colony keeps the entire sealed-brood mite population in a bee population less than half its former size, so its mite-to-bee ratio can rise sharply until the brood break takes effect - and it is the colony you still own. Field trials show the benefit of swarming for mite numbers is small, inconsistent between seasons and not dependable. The swarm carries mites and, more importantly, their viruses, and deformed wing virus load is what kills, so a low mite count is not a low virus load. You lose the crop and most of the workforce, escaped swarms establish feral reservoirs that reinfest the neighbourhood by drift and robbing, and swarms in settled areas are a nuisance and a liability that damages every beekeeper nearby.

The legitimate use of the same biology is the deliberate brood break: cage the queen for 21 to 25 days (or split, or requeen and treat once no sealed brood remains), then treat in the broodless window with oxalic acid, which is highly effective against phoretic mites and does not penetrate cappings. Whatever you use, verify afterward with a mite count, because with the amitraz-resistance mutation now widespread — at or near universal in some heavily-sampled operations, though regional surveys show real variation — an unverified treatment is an assumption, not a control.

4.9 Absconding

Absconding is the entire adult population leaving, abandoning brood and often stores, to escape conditions the colony judges intolerable. It is not reproduction: one unit departs, not two, and what remains is not a colony but combs of dying brood. Abandoned brood is the diagnostic - a colony that swarmed leaves bees behind tending brood, while a colony that absconded leaves brood with nobody on it.

The regional triggers are specific and mostly manageable. **Small hive beetle** leads: *Aethina tumida* larvae tunnel the comb and the yeast they carry ferments the honey into the characteristic orange slime, whose odour repels bees, and once slime-out is underway a colony can leave within days. The colonies at risk are those with more comb than bees to patrol it, which is why over-supering a weak colony is a real hazard. **Wax moth** does the same to undefended comb, though it usually follows weakness rather than causing it. **Starvation in dearth** matters because the midsummer dearth here is severe, and dearth simultaneously suppresses reproductive swarming and raises absconding risk. Then **heat** in unshaded apiaries with poor ventilation, **ants**, particularly fire ants working weak colonies and nucs, and **repeated heavy disturbance** - rough or frequent inspections, repeated moves, livestock knocking the stand, a skunk at the entrance nightly. Newly hived swarms and packages are the most abscond-prone, having nothing yet invested, and African-derived colonies abscond far more readily at every level of provocation.

Because the cause is environmental, an empty hive with brood abandoned in the combs is not a swarm to be recorded and forgotten. It is evidence of a stressor almost certainly acting on the hives beside it, so check the neighbours for beetle larvae, stores, shade and ants before you lose a second colony.

4.10 After the Swarm, and the Regional Calendar

A colony that swarmed and requeened itself is functional but demographically behind. It lost more than half its workers on the day, then produced no eggs for about three weeks while the virgin emerged, matured and mated. The last of the old queen's brood emerges around three weeks after departure, at which point emergence stops while the new queen's first brood is still three weeks away, so the colony bottoms out about five to six weeks after the swarm and only then climbs.

A colony three weeks out with a laying queen and half the population of its neighbours is therefore exactly on schedule and needs time, not intervention. Support the recovery with space matched to the bees rather than generous space they cannot defend, adequate stores through the trough, and, from a strong donor of verified health, a frame or two of emerging brood - the right form of help because it becomes adult bees within days without demanding nurse resources the recipient lacks. Do not requeen it, since a newly mated, accepted queen is not the limitation and killing her costs money and risks rejection; do not treat it for a disease it has not been shown to have; and do not combine it with your strongest colony merely to build one big unit, because combining is the answer for a hopelessly queenless or failing colony, not for one on a normal recovery curve. Accept that it may make little or no surplus this season.

The regional calendar changes the dates on all of this. Red maple begins in January in the warmer coastal plain, followed by willow, elm, henbit and the early brassicas, and colonies that wintered strong carry brood on eight frames while northern colonies are still clustered. Seven-day swarm inspections therefore begin in mid-to-late February in the coastal plain and Gulf coastal areas, early-to-mid March in the piedmont, and late March or April in the southern Appalachian mountains - a month or more earlier than most published calendars advise. Manipulations that must precede cell building, such as checkerboarding, reversing, opening the brood nest and the first supers, fall in late winter here; bait hives go out before the first inspections; equipment must be built before Christmas. The season is bracketed: a reproductive-swarming window from late winter through the end of the spring flow, then a distinct absconding window in the hot midsummer dearth, with a smaller swarming window occasionally appearing in a goldenrod and aster fall flow.

4.11 Numbers to Know Cold

Figure	Value	Why it is that value
Egg to sealed queen cell	8 days	Queen larvae are fed royal jelly continuously and develop fastest; this sets the inspection cadence
Egg to emerged virgin	16 days	Shortest development of the castes; worker 21, drone 24
Swarm-season inspection interval	7 days	Shorter than the 8-day egg-to-capping window, so no cup can be capped between visits
Prime swarm departure	At or just after capping, day 8	The colony will not leave until a replacement queen is queued

Figure	Value	Why it is that value
Workers leaving with a prime swarm	Over half	The swarm must draw comb and rear brood immediately
Age bias of swarm bees	Skewed young (median age below that of bees left behind), but scouts are older, experienced foragers (Gilley 1998)	Wax secretion and brood feeding are young-bee tasks
Queen weight loss before swarming	About 25 percent	Workers withhold food and shake her so she can fly
Prime swarm to first afterswarm	About 8 days	The first virgin emerges 8 days after capping
Interval between successive casts	1 to 3 days	Each virgin is released in turn
New queen begins laying	About 24-30 days from the egg	Emergence, maturation, mating and onset of lay stack up
Parent colony population trough	5 to 6 weeks after the swarm	Three weeks with no eggs, then three more before new brood emerges
Queen cups in a normal colony	10 to 20 or more	Cups mean nothing; a charged cup with an egg or larva does
Swarm vs supersedure cell count	10 or more vs 1 to 3	Swarm cells serve the prime swarm and successive casts; supersedure needs one queen
Preferred cavity volume	About 40 liters	Room for stores without excessive thermoregulatory cost; a 10-frame deep is about this
Preferred entrance	10 to 30 square centimeters, low in the cavity	Defensible against robbers and predators; comb is built downward above it
Preferred height and distance	About 5 meters up; a hint of a preference for more than about 300 m from the parent	Height reduces ground predation; distance reduces competition
Scouts and quorum	Several hundred searching; about 10-20 at a site decides it	A small experienced minority decides for the cluster
Phoretic share of the mite population	A sixth to a quarter during brood rearing	Only this fraction can leave with a swarm
Demaree follow-up inspection	7 to 9 days after the manipulation	Cells above the excluder must go before a virgin can emerge, from about day 10

Figure	Value	Why it is that value
Workforce turnover after requeening	About 6 weeks	Existing workers die off and are replaced by the new queen's daughters
Swarm season opening, coastal plain	Late February	Red maple and willow bloom here in January

4.12 Common Misconceptions

Misconception: Bees swarm because they run out of food and divide to go find more. **Correction:** Swarming is a reproductive response to prosperity, requiring incoming forage, a young-bee surplus and drones, and it peaks during build-up and the early flow. Dearth suppresses reproductive swarming; what it raises is absconding risk, a different event.

Misconception: Cells low on the comb are swarm cells and cells on the face are supersedure cells; that is how you tell. **Correction:** A useful default and an unreliable rule. Emergency cells are also on the face, congested colonies build swarm cells on the face, and a colony can run two processes at once. The reading comes from queen presence, eggs, congestion, brood pattern, drones and season.

Misconception: A colony swarms once its new queen has emerged and mated, so both halves stay queenright. **Correction:** The prime swarm leaves at or just after the *capping* of the first cells, around day 8, with the old mated queen. The parent has no laying queen for about three weeks, and that gap is why a swarm costs a crop.

Misconception: Adding supers is all the swarm control a colony needs. **Correction:** Storage space reduces backfilling but does not by itself open the brood nest around the queen. A colony whose brood nest is already backfilled will build cells with three empty supers on it. The reliable manipulations act on the brood nest itself.

Misconception: If I find and cut every queen cell, I have stopped the swarm. **Correction:** You removed the symptom and left the cause. Cells are recharged within days, one is always missed, and if the colony has already swarmed you may have destroyed its only route to a queen. Cell destruction belongs inside a manipulation that relieves congestion, never alone.

Misconception: An afterswarm is the rest of the colony finally giving up and leaving. **Correction:** An afterswarm is a cast headed by one or more virgin queens, smaller than the prime swarm, issuing about eight days after it and at one- to three-day intervals thereafter. Casts are what drive a colony below viability, which is why the post-swarm action is to reduce cells to one or introduce a mated queen.

Misconception: Splitting is always better than Demareeing because it guarantees no swarm. **Correction:** A split is more reliable and costs the crop. Surplus is what remains after maintenance, and maintenance does not halve when the colony does, so one large colony beats two medium ones on the same flow. For honey, Demaree; for increase, or when weekly inspection is impossible, split.

Misconception: A Demaree is a one-visit manipulation. **Correction:** The brood moved above the excluder is queenless and starts emergency cells immediately. You must return in seven to nine days and

destroy them; they will already be capped by then, but no virgin can emerge before about day ten. Skipping that visit is the standard way to strand a virgin above an excluder.

Misconception: Giving a new swarm a frame of open brood is free insurance. **Correction:** The anchoring effect is real, but the frame carries everything the donor carries - foulbrood spores, viruses, Nosema, mites - into a swarm that was starting clean. Take it only from a verified colony, or confine the queen briefly with an excluder and feed instead.

Misconception: Letting colonies swarm is natural mite control. **Correction:** The swarm's load is reduced but not zero, and its virus load travels with it. The parent's mite-to-bee ratio can rise sharply until the brood break takes effect, since the sealed-brood mites remain with a halved bee population, and field trials show the mite benefit of swarming is small and inconsistent between seasons. You also lose the crop, seed feral reservoirs and create a public nuisance. The proper version is a deliberate brood break plus oxalic acid, verified by a follow-up count.

Misconception: An empty hive with brood left in the combs means it swarmed. **Correction:** It absconded. Swarms leave bees and tended brood; absconding colonies abandon brood. Treat it as evidence of a stressor - beetles and slime-out, wax moth, starvation, heat, ants, disturbance - probably acting on the rest of the yard.

Misconception: A colony that swarmed and is now weak should be requeened so it catches up. **Correction:** A newly mated, accepted queen is not the problem; demography is. The colony carries a three-week egg gap and bottoms out five to six weeks post-swarm. Give it space matched to its size, stores, and a frame of emerging brood from a healthy donor.

4.13 Self-Check Questions

- A colony is boiling with bees in early March in the coastal plain, drones are flying, nectar is coming in, and eight cells are capped on the bottom bars. Name the conditions that had to be true simultaneously, and explain the mechanism by which crowding contributes.
- Explain precisely why the swarm-season inspection interval is seven days and not ten.
- Distinguish a prime swarm from an afterswarm on four axes, and state the management objective once a prime swarm has already left.
- You find two sealed cells on a comb face, a spotty brood pattern with drone brood in worker cells, no eggs, and ordinary population. Give your reading and action, and say what further observation would most change it.
- Describe a Demaree in enough detail for another beekeeper to perform it, and state its principal failure mode and when it occurs.
- Why does a split usually cost the honey crop when a Demaree does not, given that both relieve congestion?
- Explain how a Pagden artificial swarm satisfies the swarming impulse, and list the three things the beekeeper must do for it to work.

- A beekeeper no longer treats for mites because his colonies swarm each spring and the brood break handles it. Give three reasons this fails, and describe the legitimate version of the idea.
- Specify a bait hive: volume, entrance, height, orientation, contents, siting and deployment date, with a reason for each.
- State the diagnostic difference between a swarm and an absconding event as seen in the abandoned hive, list four regional absconding triggers, and explain what the finding obliges you to do next.
- A colony swarmed 21 days ago and now has a laying queen and half the population of its neighbours. Explain the arithmetic, give your management, and say why requeening would be a mistake.

4.14 Self-Check Answers

- Congestion of the brood nest, a surplus of nurse bees under about ten days old, a strong incoming flow, and a mature drone population, on top of a queen whose age and stock predispose the colony. Crowding works two ways at once: the queen's fixed pheromone output is divided among more bees, so each bee's share of QMP and footprint pheromone falls below the level that inhibits cup provisioning; and the press of bees plus backfilled nectar restricts her movement, so she lays less and over less comb.
- Because a cell goes from egg to sealed in eight days and the colony leaves at or just after capping. On a seven-day cycle, a cup charged the day after you close the hive is still open when you return. On a ten-day cycle that same cup can be charged, capped and the swarm gone before your next visit, leaving you with sealed cells, a missing queen, and no way to know how long she has been gone.
- The prime swarm carries the old mated queen, a cast one or more virgins. The prime swarm is much larger, taking over half the workers. The prime swarm leaves at capping, the first cast about eight days later, further casts at one- to three-day intervals. Casts can drive the parent below viable strength. Once the prime swarm has gone the objective is limiting casts - reduce to one good cell, or destroy all cells and introduce a mated queen.
- This reads as supersedure: few cells, comb face, ordinary uncongested population, and a pattern consistent with a failing or poorly mated queen. If drones are flying and the season allows mating, leave it alone, since the colony is correcting a real problem. The observation that would most change the reading is eggs together with a congested, backfilled brood nest and a large population, which would point to swarming despite the cell position.
- Leave the queen in the bottom box on one or two frames of open brood, the rest drawn comb or foundation. Place an excluder above her, usually with a honey super between. Move the great majority of the sealed brood, on its combs, above the excluder, and destroy any cells present. The failure mode is the follow-up: brood above the excluder is queenless and starts emergency cells within a day or two, which must be destroyed seven to nine days later, while still sealed, before any virgin can emerge from about day ten.
- Because surplus is what remains after a colony pays its own maintenance, and that cost does not halve when the colony is halved, so one very large colony directs a much greater proportion

of its foraging into surplus than two medium ones. A Demaree keeps the whole population working the flow as one unit while relieving congestion around the queen, whereas a split divides the workforce and, made just before the main flow, normally forfeits the crop from both halves.

- The parent is moved aside and a box holding the queen on a single cell-free frame goes on the original stand, so foragers returning to the old site join her and form a unit with the mated queen, the full flying force, and no brood or cells - the natural population split, reproduced deliberately. The beekeeper must find and move the queen without cells; must reduce the parent's cells to one good cell or it will cast; and must account for the parent's loss of all its foragers with stores and time.

- The parent retains all the sealed-brood mites in a bee population less than half its former size, so its mite-to-bee ratio can rise sharply until the brood break takes effect, and field trials show the mite benefit of swarming is small, inconsistent and not dependable. The swarm still carries phoretic mites and their viruses, and virus load rather than mite count is what kills. And he loses the crop and the bees, while escaped swarms become unmanaged feral reservoirs that reinfest the neighbourhood. The legitimate version is a deliberate brood break - a split, a caged queen or a requeening - followed by oxalic acid in the broodless window, verified by a post-treatment count.

- About 40 liters, supplied by a ten-frame deep, because that is the preferred volume. An entrance of 10 to 30 square centimeters low in the box, because small entrances are defensible and comb is built downward above the entrance. Mounted as high as is safely retrievable, since scouts prefer height, facing south or southeast. One frame of old dark comb for the comb odour, plus lemongrass oil whose citral mimics Nasonov components. Sited away from your apiary, deployed before the season opens - late February in the coastal plain - and checked weekly.

- A swarmed colony leaves bees behind tending brood; an absconding colony leaves brood abandoned with no adults on it. Regional triggers include small hive beetle infestation and slimed comb, wax moth destruction of undefended comb, starvation in the summer dearth, extreme heat in an unshaded apiary, ant pressure, and repeated heavy disturbance. Because the cause is environmental and local, it is almost certainly acting on the neighbouring hives too, so check the rest of the yard for beetle larvae, stores, shade and ants.

- It lost more than half its workers on the day it swarmed, then produced no eggs for about three weeks while the virgin emerged, matured and mated. The last of the old queen's brood has just finished emerging, so emergence has stopped while the new queen's first brood is still three weeks away, and the colony bottoms out around five to six weeks post-swarm. Management is support: space matched to its population, stores, and a frame or two of emerging brood from a verified donor. Requeening would destroy an accepted queen and fix nothing, because the queen is not the limitation.

4.15 Further Reading

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- University of Georgia Cooperative Extension and the Georgia Master Beekeeper Program: swarm prevention, small hive beetle and the southeastern beekeeping calendar.
- Clemson Cooperative Extension, Home and Garden Information Center: fact sheets on honey bee swarms and swarm removal.
- University of Florida IFAS Honey Bee Research and Extension Laboratory: publications on absconding, small hive beetle and African-derived honey bees.
- NC State Extension Apiculture Program: seasonal management and swarm-control publications.
- Wright, W. “Swarm Prevention Alternative – Checkerboarding Results and Conclusions” (1996), Beesource Point of View archive (also his “Nectar Management” pages) - field-derived rather than experimental, and the primary statement of the method.

Chapter 5. Genetics, Stock Selection & African-Derived Bees

Covers exam questions Q86-Q102.

5.1 Orientation

Honey bee genetics is strange in three specific ways, and nearly every master-level question here tests one of them.

The first is haplodiploidy. Males come from unfertilized eggs and carry one set of chromosomes; females come from fertilized eggs and carry two. That reorganizes relatedness inside the nest, produces diploid drones and the spotty brood of inbreeding, and makes sex determination a management concern rather than a curiosity.

The second is that the colony, not the bee, expresses the trait. Gentleness, honey yield, hygienic behavior, mite tolerance, swarm tendency - all are produced by tens of thousands of workers, half of whose genes came from drones the breeder never chose. You select a queen, you measure her colony, and the thing measured is not the thing selected.

The third is open mating. A breeder controls the maternal line completely and paternity essentially not at all. Stock does not stay bought, which is why resistance fades in open-mated daughters, why F1 hybrids disappoint in the second generation, and - seen from the other end - why African-derived genetics enters an apiary without a single colony being acquired. That last topic closes the chapter. It is not a separate subject; it is these three ideas viewed from outside.

5.2 Haplodiploidy and the Arithmetic of Relatedness

A drone has a mother, no father, and one set of 16 chromosomes. He cannot halve what is already haploid, so spermatogenesis proceeds without a reduction division: every sperm he produces is identical to himself.

That is the engine of the three-quarters figure. Two workers with the same father received his entire genome, so they share all their paternal genes; maternally they are ordinary diploid siblings and share half. Each parent contributes half the genome, so full sisters are related by (0.5 x 1.0) + (0.5 x 0.5) = 0.75. Half sisters, sharing only the maternal contribution, are related by 0.25. A queen is related to any daughter by 0.5.

Because a queen mates many times, a colony is a mosaic of full-sister subfamilies inside a much larger pool of half sisters, and average relatedness across the worker force falls well below 0.75. That dilution flips the incentives around male production. A worker is related to her own son by 0.5, a full sister's son by 0.375, a half sister's son by 0.125, and the queen's son - her brother - by 0.25. Under polyandry the average other worker's son is a poorer genetic bet than a brother, so workers destroy each other's male eggs. That is worker policing, and it is why laying workers become conspicuous only after prolonged queenlessness, when pheromonal inhibition and policing have decayed together.

A classic trap: drones from one queen are not identical. Each unfertilized egg is still a meiotic product with recombination, so each drone carries a different random half of her genome, and drones of one queen are related by 0.5, not 1.0. Drone comb in a single drone-mother colony narrows paternity without making it uniform. Only instrumental insemination with semen from one drone eliminates paternal variance - and that is a research tool, not a production practice.

5.3 Polyandry: What Within-Colony Diversity Buys

Naturally mated queens mate with roughly a dozen to two dozen drones, averages clustering in the low-to-middle teens, the documented range running from one to forty or more.

The payoff is that patrilines differ in the stimulus intensity at which their members switch on a task. A uniform colony has one threshold and responds all-or-nothing: nothing, nothing, everyone at once, overshoot. A diverse colony recruits workers progressively as the stimulus rises.

Thermoregulation is the cleanest demonstration: colonies from multiply inseminated queens hold brood nest temperature in a distinctly narrower band than colonies from single-drone queens, which oscillate. Brood reared outside roughly 91 to 96 degrees F emerges with impaired learning, flight and longevity, so the band matters.

The fitness demonstration is equally direct. Comparing colonies from queens inseminated with fifteen drones against one, the diverse colonies built about 30 percent more comb and stored 39 percent more food in the first two weeks, foraged 27 to 78 percent faster on most mornings sampled, and by late summer held roughly 26,700 workers against about 5,300. No uniform colony survived past mid-December; a quarter of the diverse colonies were alive the following May. Diverse colonies also carry lower pathogen loads, since no one pathogen genotype finds every patriline equally susceptible. Any program that narrows within-colony diversity pays for it in colony performance.

5.4 The csd Locus, Diploid Drones, and the Brood Pattern That Is Not a Disease

Sex is determined not by ploidy directly but at a single locus, the complementary sex determiner (*csd*). Heterozygous at *csd*, an individual develops as a female. Carrying one copy - hemizygous, as a drone from an unfertilized egg is - it develops as a male. Diploid but **homozygous**, it also develops as a male: a diploid drone.

Diploid drones are viable in the egg but not tolerated. Nurse bees consume the larvae within a few hours of hatching, so the beekeeper never sees dead larvae. What appears is an otherwise normal brood area with cells scattered through it that are simply empty - shot brood, or pepperpot.

Carry the arithmetic. If a mating population holds a equally frequent *csd* alleles, a random drone carries one of the queen's two with probability $2/a$, half of those offspring are homozygous, so the expected loss of fertilized eggs is $1/a$ and brood viability is $V = 1 - 1/a$. With 19 circulating alleles, viability is about 95 percent and nobody notices. Run it backwards for a field estimate: effective allele number is roughly 100 divided by the percentage of empty cells. A closed-line colony with a quarter of its cells empty

implies an effective count near four - a very small mating pool. Sib mating is the ceiling: every son of a queen carries one of her two alleles, so mating her to her brothers gives 50 percent diploid brood.

The differential diagnosis is the examinable part. European foulbrood kills larvae before capping and leaves twisted, discolored remains. American foulbrood gives ropiness, sunken perforated cappings and adhering scale. Chilled brood kills a contiguous patch at the cool periphery and leaves bodies. A pollen-bound nest has cells visibly full of beebread. Parasitic mite syndrome comes with mites. A failing queen lays erratically or lays drones. Diploid drone removal is the diagnosis of exclusion when everything is clean, mite counts are negligible, and the queen lays steadily into cells that then come up empty.

Globally there is no shortage of *csd* alleles - sequencing has identified at least 87 variants, and modelling suggests a worldwide total of roughly 115 to 145, far above the ~19 estimated for a single local population. The risk is local and self-inflicted: a closed line, a handful of breeder queens, selection hard enough to collapse the effective population size. The remedy is unrelated genetics, which is why closed programs maintain many independent lines and rotate matings among blocks rather than breeding best to best.

5.5 Hygienic Behavior and Its Assays

Rothenbuhler's crosses in the early 1960s are foundational because they proved a *behavior* was heritable and therefore selectable. Working with a line that removed dead brood and a line that did not, he showed through controlled crosses and backcrosses that the behavior separated into uncapping and removal, and that a colony could be non-hygienic by failing at either step. His two-locus model was elegant and too simple - modern mapping finds several quantitative trait loci of modest individual effect. The model was wrong, the demonstration was right, and it is why selected hygienic stock exists.

The standard assay is the freeze-killed brood test. Set a cylinder about 3 inches across over sealed brood containing fewer than about 30 unsealed cells, enclosing roughly 160 cells. Pour in about 10 fluid ounces of liquid nitrogen in two or three additions, return the frame, and at 24 hours count cells still sealed. Removal of 95 percent or more within 24 hours, on two consecutive tests, defines a hygienic colony; the original protocol read at 48 hours, and older sources still quote it. Two tests matter: scores for one colony vary substantially with strength, forage and season, so a single high score is not evidence. A freezer substitutes - cut a brood section, freeze overnight, refit it - at the cost of labor and comparability. The pin-kill test, piercing 50 to 100 sealed cells and scoring at 24 hours, is cheap and correlates less well, partly because the puncture is itself a cue.

Be clear what the assay predicts. High scores track resistance to chalkbrood and American foulbrood well, because both kill brood in the cell. They track Varroa resistance only weakly, because detecting a dead pupa is a different sensory problem from detecting a living, reproducing mite under an intact capping over a healthy pupa.

5.6 Varroa Sensitive Hygiene: What It Actually Measures

VSH is the detection of sealed brood cells containing *reproducing* Varroa foundresses and removal or disturbance of their contents, causing those mites' reproduction to fail. It acts on capped brood, with

removal strongest on young to mid-aged pupae (unpigmented to lightly pigmented), and the assay reads mite reproduction on pupae about 7 to 11 days after capping, when any offspring are present and countable.

The trait was first named suppression of mite reproduction, because infested cells in selected colonies held a strikingly high proportion of foundresses with no offspring. The mechanism was misread, though it is not yet fully resolved either: reproduction is not simply suppressed, and the leading explanation is that successfully reproducing foundresses are removed, leaving the non-reproductive ones as survivors of a cull — but recent work (Sprau et al. 2021; a 2024 study in Ecology and Evolution) found that mite offspring are not a necessary trigger for removal and that brood removal does not by itself produce non-reproduction in relocated mites, so non-reproduction may reflect more than a culling residue. Hence both the renaming and the measurement: VSH is scored as the proportion of foundresses in sealed brood that failed to reproduce, because removal of infested pupae is the primary mechanism and that proportion is its footprint, though how much of the non-reproduction is a by-product of removal is still debated. Strongly selected colonies run roughly 80 to 100 percent non-reproductive against roughly 15 to 25 percent in unselected controls. A field score opens cells until five reproductive mites are found or 100 cells examined; 80 percent or more non-reproductive is excellent, 50 to 80 percent is worth breeding from, under 20 percent is poor.

VSH is not grooming and not general hygiene. Grooming acts on phoretic mites and is scored from the proportion of fallen mites showing chewed legs or damage. General hygiene acts on dead brood and is scored by freeze-killed brood. All three are inherited separately, and a supplier selecting for one is not selecting for the others - ask which is measured and how.

5.7 Named Stocks, Honestly

A stock name describes a breeding history and a set of tendencies, not a guarantee. Variation between breeders within a stock often exceeds the differences in the catalog copy, and an open-mated queen of any stock is half local.

Stock	Appearance	Genuine strengths	Genuine weaknesses
Italian-derived	Light, yellow banding	Prolific, excellent comb builders, gentle, large populations for a long season	Rear brood late into fall and eat stores doing it; prone to robbing; poor restraint in dearth
Carniolan-derived	Dark	Very rapid spring build-up keyed to forage; frugal in dearth; winter in small clusters; gentle	Swarm-prone during the build-up; the responsiveness that makes them frugal makes them volatile
Caucasian-derived	Dark, grey	Gentle, long tongues, good in cool springs	Very heavy propolis; slower build-up; historically more nosema-susceptible

Stock	Appearance	Genuine strengths	Genuine weaknesses
Buckfast	Variable, brownish	Composite of many subspecies; productive, gentle, low swarming, selected against acarine	Sold as a controlled cross; second-generation daughters segregate badly
Russian-derived	Dark to mixed	Long coexistence with Varroa in the source population; lower mite growth; frugal	Keep queen cells standing, which reads as swarm preparation; build-up tied tightly to flow
Minnesota Hygienic	Italian-type	Selected directly on freeze-killed brood removal; strong against chalkbrood and foulbrood	Hygiene toward dead brood only weakly protects against Varroa
VSH and VSH-derived, incl. Pol-line	Variable	Selected on the proportion of non-reproductive mites (a proxy for brood removal); most directly suppresses mite growth	Can be brood-disruptive; the trait dilutes fast under open mating

The Buckfast line began at an English abbey in 1919 after acarine losses reduced the apiary to a handful of colonies, founded on a surviving native-type stock crossed with imported Italian-type queens and supplemented from many subspecies over decades. The Russian-derived material entered the United States as 100 queens collected in 1997 from the Pacific coastal region of far-eastern Russia - a population that had lived with *Varroa destructor* far longer than any Western stock - held in federal quarantine and released to the queen industry from 2000, first as three selected lines, and maintained in three breeding blocks with rotational mating between blocks.

Pol-line, a VSH-derived line from the federal bee breeding laboratory in the Gulf coastal southeast, is the best-documented modern resistant stock. In a multi-site commercial trial, untreated Pol-line colonies overwintered at about 62.5 percent against about 3 percent for untreated standard stock; with fall and winter treatment, about 72 percent against about 56 percent. Note the shape of that result: the advantage is largest exactly where the beekeeper is not treating, and it does not make treatment irrelevant.

5.8 Selecting in Your Own Apiary

Because traits are expressed by workers, a queen's own body tells you almost nothing about her breeding value. The individual selected is not the individual measured, and the measurement is confounded by paternity nobody controlled. So a line is never judged from one hive: serious programs test many daughter queens at multiple sites, because site and season swamp genotype in any single comparison, and each daughter's matings are one draw from a distribution.

Fifty colonies is enough to start. Evaluate every one across a full season against fixed criteria: temperament and calmness on the comb, honey production, brood pattern quality, mite population

growth from consistent alcohol wash counts on a set schedule, disease incidence, spring build-up, and overwintering outcome. The essential records are dated, colony-by-colony entries covering queen source and age, brood assessment, mite counts before and after every treatment, treatments and dates, honey harvested, temperament score, and whether the colony wintered. Without them, selection is memory, and memory favors whichever colony was inspected on a good afternoon.

The pre-and-post mite count matters beyond selection. Recent screening found the amitraz-resistance mutation (Y215H in the octopamine receptor gene) in every one of 39 mites screened from 18 colonies in five commercial operations that relied on amitraz (Lamas and colleagues, 2026, investigating the 2024-25 losses), up from roughly 66 percent in earlier regional surveys. A beekeeper who treats and does not verify may be running an uncontrolled mite population while believing the colony is covered - and will also mis-score that colony as mite-tolerant.

Rear queens from the best colonies over one season and preferably two, by grafting or notching, and distribute the daughters rather than concentrating them. Requeen or cull the poorest. Place drone comb in your best colonies, understanding that this shifts the odds and never determines paternity.

Resist selecting hard on one trait. Traits are genetically correlated, so intense selection on maximum honey yield can drag defensiveness, swarming tendency or wintering ability along in directions you did not intend; correlated response is the standard caution in quantitative genetics. Narrowing diversity compounds the hazard twice over - you lose the colony-level benefits of polyandry, and in a small closed population you begin losing *csd* alleles. Serious programs weight several traits in a selection index.

5.9 Open Mating, Feral Drones, and the Limits of Selection

A virgin mates in flight at a drone congregation area: a persistent aerial site roughly 30 to 200 metres across and 10 to 40 metres up, returning to the same landscape position year after year, visited by thousands of drones in a day, up to about 11,000 at the largest, drawn from up to a couple of hundred colonies. Most drones fly less than about three miles to reach one, and the great majority of matings occur within about five miles of the virgin's hive. That radius is the mating population - your colonies, your neighbors', and every feral colony in the area.

Purchased resistant stock fades in open-mated daughters. Mite resistance is polygenic and expressed by workers, whose fathers are local drones. Each generation of open mating replaces selected paternal alleles with a sample of the local population, so the trait regresses toward the local mean. It is not lost in transport, not carried in the queen's body, not an artifact of the breeder's management. It is dilution, and it is arithmetic.

F1 hybrid queens do not breed true. A purchased F1 performs well because she is a controlled cross between differentiated lines and benefits from heterosis. Her daughters are an F2: parental combinations segregate, hybrid vigor is not reconstituted, and each daughter then mates locally. Widely variable daughter colonies, some noticeably more defensive, are the expected outcome, not evidence of a mislabeled queen.

Feral colonies are in your breeding program whether you like it or not. They contribute drones to the same congregation areas and father a share of workers in every open-mated colony nearby. They are

also reservoirs of Varroa and virus and a source of mite immigration, and in affected parts of the southeastern US they may carry African-derived genetics that enter managed stock through those matings with no colony changing hands. A captured feral swarm should be kept apart, monitored, assessed over several inspections, and usually requeened.

You control the maternal line completely and cheaply. You do not control paternity. The only real answers are instrumental insemination, which delivers semen from a chosen set of drones and underlies every serious research line; a genuinely isolated mating area, meaning an island or a valley with several miles of bee-hostile terrain in every direction and no beekeepers inside that radius; or a program that organizes controlled matings collectively.

This is why trading miticide for genetics fails so routinely. Three operational conditions must accompany the stock change. First, continued quantitative mite monitoring against defined action thresholds - that the stock holds mite growth down is a hypothesis about your colonies, so test it and treat the ones that underperform. Second, control of mite immigration, since resistance suppresses reproduction inside the colony and does nothing about mites walking in from a collapsing hive next door; that needs apiary-level and ideally area-wide thinking about failing colonies, hive density, drift and neighboring beekeepers. Third, maintenance of the genetics, by requeening from the resistant source on a defined schedule or joining a controlled-mating program. The common failure mode is adopting resistant stock and quietly abandoning monitoring, which converts a promising strategy into an untested assumption, usually discovered the following winter.

5.10 African-Derived Honey Bees: Origin, Spread and Biology

Colonies of the African subspecies *Apis mellifera scutellata* were imported to South America in the mid-1950s for a breeding program meant to improve performance under tropical conditions, and swarms escaped in 1957. The resulting population hybridized with resident European-derived stock and spread north through South and Central America on the order of 200 to 300 miles a year, reaching the southwestern US border region in 1990 and subsequently expanding into parts of the southern and southeastern US, with established populations confirmed in Gulf coastal areas of the southeast by the mid-2000s.

Two mechanisms drive the spread. Colony movement - swarming and absconding - carries whole colonies across the landscape. Gene flow carries the genetics with no colony moving at all, as drones from African-derived colonies mate with European-derived queens at shared congregation areas. The practical implication is the one beekeepers miss: someone who never buys, catches or is given such a colony can still find this year’s open-mated daughters heading noticeably more defensive colonies, because the drone pool changed. Note also that the population in the Americas is a hybrid swarm whose African-derived ancestry varies continuously; the term describes a gradient, not a clean subspecies boundary.

Biologically these bees average slightly smaller - on the order of 10 to 20 percent by some morphometric measures - and develop marginally faster, workers emerging around 19 to 20 days instead of 21. They nurse for less time and forage younger. Their colonies build smaller nests, store less

honey relative to brood, and accept a far wider range of cavities including small and exposed ones, which is why they generate structural-removal calls out of proportion to their numbers. African-derived colonies swarm far more often than European-derived ones - Extension sources put it at about 4 to 12 swarms a year, often more than 10 (Texas A&M AgriLife; UF/IFAS IN790), against one to three a year for European-derived colonies - and they abscond readily - abandoning the nest entirely in response to dearth, disturbance, pest pressure or fire - which European-derived stock rarely does.

The defensive differences are quantitative, not categorical. Guards are roughly seven times more likely to fly out and sting rather than merely release alarm pheromone. For an identical stimulus, African-derived colonies deliver on the order of 4 to 10 times more stings and pursue with 10 to 30 times more bees. The defended zone extends 100 metres or more from the nest against something nearer 50 metres or much less, pursuit may continue for hundreds of metres, and agitation persists for hours after a disturbance.

The venom is not more potent. Sting for sting the chemistry is comparable; the hazard is dose. Most healthy adults tolerate 15 to 25 stings without special treatment, and a median lethal dose for a non-allergic person is usually estimated near 19 to 20 stings per kilogram of body weight - over a thousand stings for an average adult, far fewer for a child or anyone with cardiovascular compromise, and deaths have followed a few hundred stings in vulnerable people. An allergic person is at risk from one sting of any stock, which is a separate matter. Finally, African-derived populations generally sustain lower Varroa growth and persist untreated: a real resistance phenotype, genetically entangled with the traits that make the stock unmanageable, and a textbook case of correlated response.

5.11 Identification and the Requeening Response

Identification cannot be done reliably by appearance or by a single behavioral observation. Color fails because commercial European-derived stock spans very dark Carniolan and Caucasian lines to bright yellow Italian ones, and African-derived bees sit inside that range. Size fails because the average difference is real but the distributions overlap heavily; one forager's wing measurement resolves nothing. Behavior fails because defensiveness varies with weather, time of day, nectar flow, queen status, recent robbing, recent disturbance and how the hive was opened.

The laboratory tools sit in a hierarchy. **FABIS** (Fast Africanized Bee Identification System) is a screen using a few easily measured characters - forewing length or worker body weight from a small sample - to sort colonies into "European" and "needs further testing." **Full morphometric discriminant analysis**, the USDA-ID method, measures many wing, leg and body characters on a larger sample and assigns it by multivariate discriminant function; this is confirmation grade. **Mitochondrial DNA assays** identify the maternal lineage only, so a European-matriline colony whose queen mated largely with African-derived drones reads European while producing substantially African-derived workers, and the reverse also occurs. **Nuclear markers and SNP panels** estimate ancestry proportion across the genome and are the standard where a quantitative answer is needed. Submit a sample to the state regulatory agency or an approved laboratory when the answer carries weight beyond your own yard - a regulatory question, a liability claim, a stinging incident.

The management answer does not wait on the test. The workers now in the colony carry the current queen's genetics and those of the drones she mated with, and nothing will change their behavior; requeening does not modify the existing bees, it replaces them by attrition. Introduce a mated queen of known gentle European-derived stock and every worker subsequently reared is her daughter. Her first daughters emerge about 21 days after she begins laying, and worker lifespan in the active season is roughly four to six weeks, so temperament begins shifting noticeably at three to four weeks, is clearly changed by about six weeks, and is essentially complete after two brood cycles - six to eight weeks from a successful introduction.

In the interim the colony must be worked with full precautions: complete protective equipment with ankles and wrists sealed, generous smoke, cool early-morning or evening timing, and a second person. Finding and removing the existing queen is the hard part and may require moving the colony to a remote site first, shaking bees through an excluder, or splitting to reduce the population handled; acceptance is poorer in a defensive colony, so a push-in cage or nucleus introduction often earns its extra step. And requeening does not address the drones already produced, which are in the landscape and will father workers in other beekeepers' open-mated colonies this season. That is why area-wide management matters, why prompt requeening is a service to everyone within five miles, and why requeening on a routine one- to two-year schedule from a known source is the standing recommendation in affected regions.

5.12 Speaking About This in Public

Communicating accurately to beekeepers and the public is an examined competency, and this is where it is tested hardest, because the two easy positions are both wrong.

Alarmism is wrong on the facts. These are honey bees, the same species, doing the same work. The venom is not special. Most people in affected regions will never have an encounter, and managed colonies headed by purchased queens of known stock are not the problem. Dismissal is also wrong on the facts, and it is the failure mode of beekeepers who resent the coverage. The behavioral differences are documented and quantitative: more bees responding, faster, from further away, for longer. People have been seriously injured and killed, mostly when machinery disturbed a nest near someone who could not get away.

The honest position is the specific one. Name the difference - degree of defensiveness, readiness to swarm and abscond, willingness to nest in odd cavities - and name the hazard: number of stings delivered quickly, not potency. Then give concrete advice. Do not disturb a nest or swarm; never seal or spray a colony in a structure yourself; if bees come after you, run in a straight line away from the nest and get inside a building or vehicle. Do not stand and swat, which spreads alarm pheromone; do not hide in water, since bees will wait; cover the face as you go; remove stings fast by any method, since speed matters and technique does not. Call emergency services for many stings or any systemic reaction. And say where certainty ends: ancestry is a gradient, temperament is situational, and across most of the region an unusually hot colony is far more likely to be a queenless, robbed-out or simply badly bred European-derived colony than an African-derived one.

5.13 Numbers to Know Cold

Figure	Value	Why it is that value
Relatedness, full sisters	0.75	Drone sperm are identical, so same-father sisters share all paternal genes
Relatedness, half sisters	0.25	Maternal contribution only: 0.5 x 0.5
Relatedness, drones of one queen	0.5	Each unfertilized egg is a meiotic product with recombination
Worker to son / full sister's son / half sister's son / brother	0.5 / 0.375 / 0.125 / 0.25	The average nephew loses to a brother under polyandry - hence worker policing
Typical mating number	~12-20 drones; range 1 to 40+	Usually 1-3 mating flights over 2-4 days
Brood viability formula	V = 1 - 1/a	1/*a* of fertilized eggs is homozygous at *csd* and removed
Diploid drone fraction, sib mating	50%	Every son of the queen carries one of her two *csd* alleles
Effective *csd* allele estimate	~100 / (percent empty cells)	Inverse of the viability formula; 25% empty implies about 4 alleles
Diploid drone larva removal	Within hours of hatching	Nurse bees eat them - you see empty cells, not dead larvae
Diversity effect, productivity	~30% more comb, 39% more food in 2 weeks; ~26,700 vs ~5,300 workers by late summer	Graded task thresholds versus all-or-nothing response
Diversity effect, winter survival	~25% of diverse vs 0% of single-drone colonies	A fitness consequence, not just a productivity one
Brood nest temperature	91-96 degrees F, narrower band when diverse	Brood outside the band emerges with impaired learning and flight
Freeze-killed brood assay	~3-inch cylinder, ~160 cells, ~10 fl oz liquid nitrogen, read at 24 h; 95% or more removed = hygienic	Enough cells for a stable percentage; 24 h is the current standard window (48 h in the original protocol)
Hygienic threshold	>95% removal on two consecutive tests	Repeat scores for one colony vary substantially
VSH, selected vs unselected	~80-100% vs ~15-25% non-reproductive foundresses	Reproducing foundresses are removed; survivors skew non-reproductive

Figure	Value	Why it is that value
VSH field score	80%+ non-reproductive excellent; 50-80% breedable; <20% poor	Open cells until 5 reproductive mites or 100 cells examined
Pol-line field trial survival	~62.5% vs ~3% untreated; ~72% vs ~56% treated	The advantage is largest where no treatment is applied
Drone congregation area	~30-200 m across, 10-40 m up; up to ~11,000 drones from up to ~200 colonies	Persistent landscape features; why paternity cannot be controlled
Mating radius	Drones mostly <3 miles (occasionally 3-4+); most matings within a few miles	Treat ~5 miles as the mating population: yours, neighbors', feral
African-derived key dates and spread	Imported 1956; escape 1957; ~200-300 miles/year; border region 1990	Escaped swarms from a tropical improvement program, then swarming plus gene flow
African-derived defensiveness	4-10x more stings, 10-30x more pursuing bees, ~7x guard response; zone 100+ m	Same venom, far greater dose delivered far faster and from further out
African-derived swarming	Commonly 4-12 swarms a year, often more than 10, vs 1-3 for European-derived	Small nests, fast build-up, tropical reproductive strategy
Requeening timetable	Noticeable 3-4 weeks, clear by ~6 weeks, complete in 2 brood cycles	Daughters emerge at ~21 days; workers live 4-6 weeks in season
Sting tolerance	15-25 tolerated by most adults; ~19-20 stings/kg estimated median lethal dose	The hazard is dose; potency does not differ by stock

5.14 Common Misconceptions

Misconception: All the drones a queen produces are genetically identical, since they come from her unfertilized eggs. **Correction:** Each egg is a meiotic product with recombination, so drones of one queen are related by 0.5. What *is* uniform is the sperm from a single drone, because a haploid male cannot perform a reduction division.

Misconception: A spotty brood pattern means disease or a failing queen. **Correction:** With no ropiness, no odor, no scale, low mites and a queen laying normally into cells that come up empty, the cause is homozygosity at *csd*. Diploid drone larvae are eaten within hours of hatching, so you see gaps rather than corpses.

Misconception: Mite-resistant stock, once purchased, is in the operation for good. **Correction:** Resistance is polygenic and expressed by workers whose fathers are local drones, so each generation of open mating dilutes the selected alleles toward the local average. Maintaining it takes scheduled replacement queens, instrumental insemination, a truly isolated mating area, or a controlled-mating program.

Misconception: Filling your yard with drone comb from your best colonies lets you control mating. **Correction:** It shifts the odds and is worth doing, but congregation areas draw drones from hundreds of colonies across several miles, including feral colonies and apiaries you know nothing about. Odds are not determination.

Misconception: An excellent F1 hybrid queen will give excellent daughters. **Correction:** Her performance came from heterosis in a controlled cross. Her daughters are an F2 in which parental combinations segregate, and they then open-mate locally. Variable daughter colonies, some more defensive, are the expected result, not evidence of mislabeling.

Misconception: Selecting hard for honey production is the efficient way to improve stock. **Correction:** Traits are genetically correlated, so single-trait selection drags defensiveness, swarming and wintering along in directions you did not choose, and it narrows diversity - costing the benefits of polyandry and, in a small closed line, *csd* alleles. Use a selection index.

Misconception: Hygienic behavior and VSH are the same trait under two names. **Correction:** General hygiene is removal of dead or diseased brood, scored by freeze-killed brood. VSH is mainly removal of sealed cells containing reproducing mites, scored as the proportion of non-reproductive foundresses. Grooming is a third, acting on phoretic mites. All three are inherited separately.

Misconception: A high freeze-killed brood score means the colony will handle Varroa. **Correction:** It predicts chalkbrood and American foulbrood resistance well, since both kill brood in the cell. Detecting a dead pupa is a different sensory problem from detecting a living, reproducing mite under an intact capping, and the Varroa correlation is weak.

Misconception: VSH colonies stop mites from reproducing. **Correction:** They remove the pupae in which mites *have* reproduced. The high proportion of non-reproductive foundresses is largely the residue of that removal - which is why the trait was renamed from “suppression of mite reproduction” - though how much of it is a by-product of removal is still debated.

Misconception: Rothenbuhler’s two-gene model is how hygienic behavior actually works. **Correction:** The architecture is polygenic, with several loci of modest effect. What the work established is that a behavior is heritable, that uncapping and removal are separable, and that the trait can be selected.

Misconception: You can tell an African-derived colony by how it acts on inspection. **Correction:** Defensiveness varies with weather, dearth, queen status, recent robbing and how the hive was opened, so one episode proves nothing. Color and size also fail, because the ranges overlap commercial stock. Confirmation needs morphometrics or a molecular assay.

Misconception: A DNA test settles the question definitively. **Correction:** It depends which. Mitochondrial assays give the maternal lineage only, so a European-matriline colony whose queen

mated with African-derived drones reads European while producing substantially African-derived workers. Nuclear markers or SNP panels give an ancestry proportion.

Misconception: Requeening an overly defensive colony fixes it right away. **Correction:** The existing workers keep their genetics and behavior until they die. The new queen's first daughters emerge about three weeks after she starts laying, and the change is essentially complete after two brood cycles - six to eight weeks.

Misconception: African-derived bee venom is more toxic. **Correction:** Sting for sting it is comparable. Far more bees respond, from further away, faster and for longer, so the delivered dose is much larger. A median lethal dose for a non-allergic person is estimated near 19 to 20 stings per kilogram - arithmetic rather than chemistry.

Misconception: A captured feral swarm is free bees and a good find. **Correction:** It is free bees of unknown ancestry, disease and mite status, and temperament. Keep it apart, monitor it, assess it over several inspections, and in most cases requeen it.

5.15 Self-Check Questions

- Derive the 0.75 relatedness figure between full sisters, and name the feature of drone reproductive biology that makes it possible.
- A queen is instrumentally inseminated with semen from a single drone and her colony performs poorly all season. Give three mechanisms by which lack of within-colony diversity produces that result.
- A colony in a closed line shows about one cell in eight empty, scattered through an otherwise normal brood area. Estimate the effective number of *csd* alleles and state the corrective action.
- Distinguish the brood appearance of diploid drone removal from early European foulbrood and from chilled brood, naming the observation that separates each pair.
- Explain why a queen's genetic merit must be assessed through her colony, and give two consequences for how a breeding program is designed.
- A breeder advertises "hygienic stock." What should you ask before buying, and why does the answer change what you can expect against Varroa?
- Describe the freeze-killed brood assay and explain why two tests are required.
- State precisely what the VSH measurement counts, and why a high proportion of non-reproductive foundresses is taken as evidence of removal rather than of suppressed mite reproduction, and why that reading is still debated.
- A beekeeper buys ten queens of a documented resistant line and grafts thirty open-mated daughters the next spring. Predict the outcome and justify it genetically.
- State the three operational conditions that must accompany a switch to resistant stock if reduced miticide use is to have a fair chance, and name the usual failure mode.

- Give the two mechanisms by which African-derived genetics spreads, and explain why the second affects a beekeeper who never acquires such a colony.
- Why is a single defensive inspection insufficient grounds to classify a colony as African-derived, and what is the correct response to a persistently, extremely defensive colony?
- You requeen a very defensive colony with a known European-derived mated queen on 1 June. Sketch the timetable of change with reasons, and state what requeening does not fix.

5.16 Self-Check Answers

- A drone is haploid and cannot perform a reduction division, so every sperm he makes is identical to himself. Two workers sharing a father share all their paternal genes; maternally they are ordinary diploid siblings sharing half. Each parent contributes half the genome, so relatedness is (0.5 x 1.0) + (0.5 x 0.5) = 0.75. Half sisters share only the maternal half, giving 0.25. Average relatedness across a whole polyandrous colony is far below 0.75, and that dilution drives worker policing of other workers' male eggs.
- Task thresholds: patrilines differ in the stimulus level at which members begin a task, so a single-patriline colony responds all-or-nothing and overshoots. Thermoregulation: uniform colonies oscillate around the brood nest set point instead of holding a narrow band, and brood reared outside roughly 91 to 96 degrees F emerges with impaired learning, flight and longevity. Disease: with one paternal genotype there is no variation in susceptibility, so a pathogen suited to it sweeps the colony. Measured outcomes include far less comb, much less stored food, small populations and failure to overwinter.
- One cell in eight is 12.5 percent, so effective allele number is roughly 100 divided by 12.5, about eight *csd* alleles - well below the roughly 19 that gives about 95 percent viability, and diagnostic of a narrowed closed line rather than disease. The correction is unrelated genetics: bring in unrelated breeder queens or drone sources, and restructure the program so lines are kept as multiple independent blocks with rotational mating between them, rather than best-to-best mating in a shrinking pool.
- Diploid drone removal leaves clean empty cells scattered through an otherwise normal brood area, with a queen laying normally and no larval remains, because nurse bees consume the larvae within hours of hatching. Early European foulbrood leaves dead or dying larvae *in* the cells, typically twisted in the coil and discolored; the separator is the presence of remains. Chilled brood kills a contiguous patch, usually at the cool periphery or on frames exposed in a cold inspection, and leaves bodies; the separator is contiguity and location rather than scatter through the center.
- Traits are expressed by workers, who take half their genes from the drones the queen mated with, and the queen's own body says almost nothing about her breeding value. The individual selected is not the individual measured, and the measurement is confounded by paternity the breeder did not control. Consequently a line must be evaluated across many daughter queens at multiple sites, because site and season swamp genotype in any single comparison; and full-season colony records are the minimum evidence, since honey yield, wintering and mite growth are separate questions.

- Ask which trait is measured and by what assay. Freeze-killed brood removal means general hygiene toward dead and diseased brood, which predicts chalkbrood and American foulbrood resistance well but Varroa outcomes only weakly. VSH, scored as the proportion of non-reproductive foundresses in sealed brood, is the trait that most directly suppresses mite population growth. Grooming, scored from damaged mite fall, is a third and separately inherited trait. Detecting a dead pupa and detecting a living reproducing mite under an intact capping are different sensory problems.

- Enclose sealed brood with a cylinder about 3 inches across, choosing a patch with fewer than about 30 unsealed cells so roughly 160 cells are covered. Pour in about 10 fluid ounces of liquid nitrogen in two or three additions, return the frame, and at 24 hours count cells still sealed. Removal of 95 percent or more within 24 hours, on two consecutive tests, defines a hygienic colony. Two tests are required because repeat scores for one colony vary substantially with strength, forage and season, so a single high score is as likely to reflect conditions as genetics.

- It counts the proportion of Varroa foundresses in sealed cells that produced no viable offspring. The behavior removes cells containing successfully reproducing foundresses, so those mites are progressively subtracted from the sampled population and the ones left to count skew heavily toward those that never reproduced. On the leading explanation, reproduction was not inhibited; the reproducers were culled, though recent work shows the mechanism is not fully settled. Selected colonies run roughly 80 to 100 percent non-reproductive against roughly 15 to 25 percent in unselected controls. The measurement is read as a footprint of removal - hence the rename from suppression of mite reproduction.

- The daughters will be genetically half local. Resistance is polygenic and expressed by workers whose fathers are drones from congregation areas drawing on every colony within several miles - the beekeeper's, the neighbors', and feral. Each generation of open mating replaces selected paternal alleles with a sample of the local population, so daughter colonies will be highly variable and their average resistance will sit well below the purchased mothers and drift toward the local mean. Remedies are scheduled replacement queens, instrumental insemination, a truly isolated mating area, or a controlled-mating program.

- First, continued quantitative monitoring against defined action thresholds, so performance is verified rather than assumed and underperformers get treated. Second, control of mite immigration through apiary-level and area-wide measures - prompt attention to collapsing colonies, sensible density, layout that limits drift, communication with neighbors - since resistance does nothing about mites walking in. Third, maintenance of the genetics by requeening from the resistant source on schedule or joining a controlled-mating program. The usual failure mode is adopting the stock and abandoning monitoring, discovered the following winter.

- Colony movement - swarming and absconding - carries whole colonies across the landscape, historically on the order of 200 to 300 miles a year. Gene flow carries the genetics with no colony moving, as drones from African-derived colonies fly to the same congregation areas as every other drone and mate with European-derived queens on their mating flights. Because a queen mates with a dozen or more drones drawn from hundreds of colonies within about five miles, a beekeeper who buys no bees and catches no swarms can still find this year's open-mated daughters heading more defensive colonies. The maternal line was controlled; the paternal sample was not.

- Defensiveness varies with weather, time of day, nectar flow, queen status, recent robbing, recent disturbance and inspection technique, so one episode describes circumstances rather than ancestry. Color and size fail equally, since commercial European-derived stock spans very dark to bright yellow and the size distributions overlap. The practical response does not depend on the answer: a colony persistently and extremely defensive across multiple inspections should be requeened with known European-derived stock, because that is correct for an unmanageable colony of any ancestry. Submit a sample to the state regulatory agency or an approved laboratory when the answer carries regulatory or liability weight.

- The workers present on 1 June carry the old genetics and will not change. The new queen begins laying within a few days of release; her first daughters emerge about 21 days later, in the last week of June. Since worker lifespan in the active season is four to six weeks, the old population declines through July while hers accumulates, so a noticeable change appears at three to four weeks, a clear change by about six weeks, and turnover is essentially complete after two brood cycles in mid- to late July. Full precautions are needed throughout. Requeening does not remove the drones the colony already produced, which will father workers in other beekeepers' open-mated colonies this season.

5.17 Further Reading

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- USDA-ARS Honey Bee Breeding, Genetics and Physiology Research Laboratory: online documentation of the Russian honey bee importation and release program, VSH, and Pol-line, at ars.usda.gov.
- Honey Bee Health Coalition, *Tools for Varroa Management*, 9th edition (2026).
- University of Georgia Cooperative Extension Bulletin 1045, *Honey Bees and Beekeeping*, including its Africanized honey bee section; also University of Florida IFAS, Clemson Cooperative Extension and Texas A&M AgriLife Extension publications on Africanized honey bees.
- eXtension Bee Health (bee-health.extension.org): “Testing Honey Bee Colonies for Hygienic Behavior” and “Africanized Bees: Better Understanding, Better Prepared.”

Chapter 6. Equipment, Apiary Design & Regional Siting

Covers exam questions Q103-Q114.

6.1 Orientation

Equipment looks like the least intellectual part of beekeeping and is examined as though it were the most. The reason is that almost every piece of woodenware in a modern apiary is a physical consequence of one biological measurement, and a candidate who understands that measurement can derive most of the rest rather than memorizing it. Boxes, frames, excluders, inner covers and bottom boards are not arbitrary industrial conventions. They are the bee's own tolerances rendered in pine.

Three ideas organize this chapter.

The first is bee space. A honey bee colony treats a gap of a particular narrow width as a corridor and any other gap as a defect to be repaired - with comb if the gap is too wide, with propolis if it is too narrow. Langstroth's insight was not that bees leave such a space but that a hive built to respect it everywhere would have removable frames, and removable frames are the whole of modern management. Every dimension downstream - box rim heights, frame rest depths, top bar thickness, the gap between comb faces - exists to hold that tolerance. Equipment faults are therefore diagnosable: burr comb and propolis are the colony telling you which way your gap is wrong.

The second is that comb, not woodenware, is the capital. Boxes are cheap and replaceable; drawn comb costs the colony honey, wax-making bees, and calendar time during a flow, and a beekeeper who loses comb to wax moth, beetle slime or a flooded apiary has lost the expensive thing. But comb is also a sink: it accumulates miticide residue, pathogen spores and cocoon debris, and so has a service life. Managing comb means holding two opposed facts at once - it is the most valuable asset you own, and you should be systematically destroying part of it every year.

The third is that a site is a set of biological conditions, not a parking space. In the southeastern US the siting variables interact in ways that are specific to the region: shade reduces heat stress but keeps the soil damp, and damp soil is exactly what small hive beetle larvae require to pupate; low ground gives shelter from wind but is also the ground that floods when a tropical system stalls; a convenient spot near the barn is also where the fire ant mounds are. The examiner is probing whether you can reason about a site rather than recite a list, and whether you know which of the standard equipment claims are demonstrated and which are merely widely repeated.

6.2 Bee Space: The Constraint That Generated the Hive

6.2.1 The measurement

Bee space is a gap of roughly 6 to 9 millimeters - about one quarter to three eighths of an inch - which bees leave open as a passageway. It is not a preference; it is a behavioral threshold with a fairly narrow range. Reduce the gap much below 6 mm and the bees treat it as a crack and fill it with propolis. Open it

much beyond 9 mm and they treat it as void space and build comb into it. The response is strongest between frames and between boxes; larger spaces below the frames, such as a deep bottom board or a slatted rack, are often tolerated.

The narrowness of that window is the entire reason the principle works as an engineering constraint. A tolerance of plus or minus a few millimeters is achievable in milled softwood, which is why an 1850s woodshop could build to it, and why a warped box or a swollen frame rest destroys it. L. L. Langstroth patented the movable-frame hive in 1852 and published *Langstroth on the Hive and the Honey-Bee* in 1853; the invention is properly described not as the discovery of bee space but as the decision to maintain it on all six sides of every frame simultaneously.

Note what the wrong answers to this question usually claim. A gap of about 1 mm is a crack, not a bee space - that is the scale at which propolis is deposited. A gap of about 25 mm is roughly the thickness of a drawn comb by itself, far wider than a passageway, and bees will build comb into it. A gap of about 50 mm is a void the colony will fill with comb within a flow.

6.2.2 Comb spacing is a different measurement

Distinguish bee space from comb spacing, because the exam sometimes conflates them deliberately. In a natural nest, worker combs are built with centers roughly 32 to 38 mm apart. That center-to-center figure is the sum of two things: the thickness of the comb itself, typically 22 to 25 mm for worker brood comb, and the bee space between adjacent comb faces. Hoffman frames in a standard Langstroth hive are self-spacing at 1 3/8 inches, about 35 mm, a manufacturing standard that falls within the natural range of worker comb spacing. So bee space is roughly 6 to 9 mm; comb spacing is roughly 35 mm; the second contains the first.

6.2.3 Top bee space and bottom bee space

The space has to be somewhere. In a **bottom-bee-space** box the frame top bars sit flush with, or nearly flush with, the upper rim, and the bee space is left below the frames, between the bottom bars and the top bars of the box beneath. In a **top-bee-space** box the frames hang lower, so the space is above the top bars and the bottom bars come flush with the lower rim. Both conventions are manufactured for Langstroth hives in the US and brands differ, so check before mixing equipment from different makers; the British National hive is bottom bee space.

Either convention works perfectly well as long as an entire stack uses one of them. Mixing them in one stack is the classic self-inflicted injury, and it produces **both** faults at once depending on the order of the boxes. Put a bottom-bee-space box on top of a top-bee-space box and the two spaces stack: a gap of roughly 3/4 inch at that junction, which the bees will fill with burr comb, so the boxes glue together and combs tear on every inspection. Reverse the order - a top-bee-space box on top of a bottom-bee-space box - and the two flush surfaces meet with no gap at all: the bees propolize the junction solid, and workers crossing between boxes are crushed when you set the super down.

6.2.4 Reading the equipment

The practical payoff of understanding bee space is diagnostic, and this is what a master-level examiner wants to see.

- **Burr comb and brace comb between boxes** means the gap at that junction is oversized. Causes: mixed bee-space conventions, a warped box rim, a frame rest worn or rabbeted too deep, frames with thin top bars, or a box run with fewer frames than it should carry.
- **Heavy propolis at a junction, and crushed bees** means the gap is undersized. Causes: swollen or paint-thickened rims, propolis buildup itself narrowing the space over years, frames pushed up by comb built on the bottom bars.
- **Comb built on the underside of the inner cover** means the space above the top bars has been lost or exceeded - commonly an inner cover rim installed the wrong way up, or a colony with no super above and a deep gap under a migratory cover.
- **Ladder comb between the bottom bars and the bottom board** in a hive with no slatted rack is normal at the front and is often the first thing a colony builds in a deep bottom board.

A beekeeper who scrapes burr comb every visit without asking which gap is wrong is treating a symptom. Equipment that is chronically fighting bee space also costs bees: every propolized junction and every torn brace comb is a disturbance, and torn brood comb is an open invitation to robbing and to small hive beetle oviposition.

6.3 Boxes, Frames and the Cost of Mixing Them

6.3.1 The standard dimensions

These are worth knowing exactly, because laboratory and field portions of master-level exams routinely ask a candidate to identify equipment and state its dimensions.

A ten-frame Langstroth body is 19 7/8 inches long by 16 1/4 inches wide on the outside, 18 3/8 by 14 3/4 inside. An eight-frame body keeps the same length and narrows to 14 inches outside, 12 1/2 inches inside. Heights are the same in both widths: deep 9 5/8 inches, medium (often called Illinois or western) 6 5/8 inches, shallow 5 11/16 inches.

Frames share a 19-inch top bar across all depths, which is what makes a frame drop into any body of the right depth regardless of manufacturer. Frame depths are 9 1/8 inches for a deep, 6 1/4 for a medium, 5 3/8 for a shallow. Hoffman end bars are 1 3/8 inches wide at the shoulder, which sets self-spacing.

A deep frame of worker comb carries on the order of 3,400 to 3,500 cells a side, so roughly 7,000 cells in the frame, and roughly 100 grams of beeswax. Those two numbers are the basis of most colony arithmetic: brood area estimates, wax yield estimates, and the honey cost of drawn comb.

6.3.2 The three-way comparison

The recurring sideline question is whether to run all deeps, all mediums, or eight-frame equipment, and the examiner is testing whether you weigh weight, interchangeability and heat together rather than arguing from tradition.

Configuration	Full box of capped honey	Interchangeable?	Principal advantage	Principal cost
Ten-frame deep	roughly 80-90 lb	Deeps only	Brood nest in one or two boxes, few junctions through the nest	Lifts are a genuine injury risk; heat stress in a suit in midsummer
Ten-frame medium	roughly 50-60 lb	Every box and frame in the operation	One frame type, one box type, one inventory	More boxes to lift and break apart; brood nest interrupted at more junctions
Eight-frame medium	roughly 40-48 lb	Within the eight-frame line	Lightest practical lift; tall narrow cluster geometry suits winter	Lower per-box capacity; more stack height; some accessories less available
Ten-frame shallow	roughly 35-40 lb	Shallows only	Light supers, traditional comb honey depth	Poor use of frame area for brood; most boxes per colony

The weight figures follow from comb volume, not from the wood. A deep frame heavy with capped honey runs around 7 to 8 pounds; ten of them plus the box lands at 80 to 90. A medium frame runs about 4.5 to 5 pounds; the same arithmetic gives 50 to 60. Eight-frame boxes are simply the ten-frame figure times eight tenths, less a little for the narrower box.

All-medium equipment is the configuration that gives full interchangeability. Any box can serve as a brood chamber, a super, a feeder shim body or a nuc component; any frame of brood can be moved into any box in the yard; you order one size of frame and one size of foundation. That last point matters more than it sounds: a two-size operation carries two inventories of frames, foundation, follower boards and excluder-fitting accessories, and it guarantees that on some Saturday you will be standing in a yard holding a deep frame of queen cells with only mediums in the truck.

The cost of all-mediums is that the brood nest is interrupted at more box junctions. Bees will cross a junction, but a junction is a discontinuity in comb, and a brood nest spread over three medium boxes has two such lines through it where a two-deep nest has one. In practice the colony copes; the cost is modest and mostly falls on the beekeeper, who must inspect three boxes instead of two.

In the southeastern US the heat argument is often decisive and is worth stating explicitly, because the examiner's rationale usually includes it. Working a yard in a full suit at 95 degrees F with high humidity is heat-illness territory. A beekeeper who must lift 85-pound boxes under those conditions will eventually either hurt a back or cut an inspection short, and the inspection that gets cut short is the one that would have caught queenlessness or a mite problem. Lighter boxes buy thoroughness. That is a bee-health argument, not just an ergonomic one.

6.3.3 Standardization is the actual decision

Whichever configuration you pick, the operational value of standardizing across the whole operation exceeds the theoretical merits of any single configuration. Standardized equipment means every box stacks on every box, every frame fits every box, every lid fits every hive, spares are generic, and a helper can be sent to a yard with a truckload of boxes without a sorting problem. Non-standard equipment means that on any given day some fraction of your inventory cannot be used where it is needed.

This is also a bee-space argument. A shed containing four frame styles, three box depths, boxes from five manufacturers and a stack of home-built bodies cut on a table saw with a dull blade is a shed full of mismatched tolerances. Home-built equipment is entirely legitimate, but it must be built to the published dimensions, including the frame rest depth, or it will generate burr comb in every hive it goes into.

The transition problem is real. Converting a two-deep operation to all mediums takes two or three seasons and is done by consistently supering with the new size, cycling deeps up and out as they empty, and culling the oldest deep brood comb first so the comb rotation and the equipment conversion pay for each other. Trying to do it in one season means either buying a full set of drawn comb you do not have or asking colonies to draw a whole nest's worth of foundation during the only flow that would otherwise have produced a crop.

6.4 Foundation, Foundationless, and What Each Does to Comb

Foundation exists to solve the reference problem. Bees building comb need something to build straight on; given an empty frame and no guide, they build catenary combs following the geometry of the cavity, not the geometry of your frame. Foundation supplies a flat plane, an embossed cell pattern, and - in wired and plastic forms - structural support against the loads of honey and centrifugal extraction.

6.4.1 Wired wax foundation

A sheet of milled beeswax embossed with cell bases, reinforced with vertical crimped wire, and either supported by horizontal frame wires or hung from a wedge top bar. Its advantages are that it is wax all the way through, so bees accept it readily even in a dearth, and that the comb drawn on it is uniformly accepted for comb honey and cut comb if unwired thin surplus foundation is used.

Its costs are handling and residue. Wax foundation sags in heat, tears if handled roughly, and requires embedding wire into it if the comb is to survive radial extraction. More importantly, commercial foundation is made from recycled beeswax from the general supply, and that wax carries the residue history of the whole industry. Mullin and colleagues (*PLOS ONE*, 2010) found that 98 percent of comb and foundation wax samples were contaminated, with fluvalinate at up to 204 ppm and coumaphos at up to 94 ppm, and 98.4 percent of combined pollen and wax samples contained two or more pesticides. A beekeeper who buys commercial foundation is importing residue at day one. This is one of the genuine arguments for foundationless comb and for wax from your own cappings.

6.4.2 Plastic foundation and one-piece plastic frames

Plastic foundation is a rigid embossed sheet, usually wax-coated, dropped into a wooden frame; one-piece plastic frames integrate the two. The advantages are mechanical and sanitary. They do not sag, they do not blow out in a radial extractor even when new, they tolerate rough handling and heat, they can be scraped back to the midrib and reused after a comb is culled, and they carry no inherited wax residue in the sheet itself - only in whatever coating is applied.

The costs are behavioral. Bees draw plastic more reluctantly than wax, particularly in marginal conditions, and a colony given plastic foundation without a strong flow and a crowded nest will often ignore it, or draw it partially, or build comb off its face. Heavier wax coating improves acceptance, and many beekeepers add a further coat of clean wax with a roller or brush. The rule is simple: plastic foundation is drawn well by a strong colony during a strong flow and badly by anything else. Give it to a swarm you have just hived during the main flow and it works; give it to a struggling nuc in the July dearth and you will get a mess.

Scraping and recoating a plastic frame is the sanitation advantage that matters. A plastic frame whose comb has been cut out, scraped and rewaxed is, for practical purposes, a new comb with no cocoon layers and no accumulated brood-nest residue - which makes plastic the most convenient substrate for an aggressive comb rotation program.

6.4.3 Foundationless

Foundationless frames give the bees a starter strip, a wedge, a bevel, or a strung guide, and let them build. Done properly - frames level, hives level, foundationless frames placed between drawn combs rather than in a block, and inspected early so any deviation can be corrected while the comb is soft - it produces the cleanest comb available: wax built by these bees this season, with no imported residue whatsoever.

There are three costs. First, discipline: an unlevel hive or a foundationless frame placed at the outside of a box will produce comb that bulges, waves or crosses from frame to frame, and cross-built comb makes an inspection destructive. Second, drone comb: given a free choice, bees build a substantially larger proportion of drone comb than foundation permits, commonly in the range of 15 to 25 percent of a foundationless nest. That is biologically normal, it supports drone production and is the basis of drone-brood trapping for Varroa, but it also multiplies mite reproductive substrate if the drone comb is simply left in place through the season. Third, structural weakness: new foundationless comb blows out in a radial extractor. Extract it tangentially, slowly, or crush and strain.

Foundationless also allows bees to build their own cell size. Standard worker foundation is embossed at about 5.4 mm across the flats; natural worker comb in *Apis mellifera* commonly runs about 5.2 to 5.4 mm and drone comb about 6.2 to 6.6 mm. The small-cell hypothesis - that foundation at about 4.9 mm shortens capped development enough to suppress Varroa reproduction - has been tested repeatedly and has not produced a consistent reduction in mite population in controlled trials. State it that way on an exam: small cell is a hypothesis with a plausible mechanism that has not been supported by controlled testing, and it should not be presented to a new beekeeper as a mite control.

6.5 Frame Spacing and the Nine-Frame Rule

A ten-frame body has 14 3/4 inches of interior width. Ten Hoffman frames at 1 3/8 inches occupy 13 3/4 inches, leaving roughly an inch of slack, which is why ten frames can be worked apart and pushed together. Spread nine frames evenly in the same space and each gets about 1 5/8 inches; spread eight and each gets about 1 13/16 inches.

Bees respond to that extra width by drawing deeper cells on the same midrib. Comb that would be about 7/8 to 1 inch thick at ten-frame spacing comes out closer to 1 1/4 inches at nine-frame spacing, because the colony maintains the bee space between comb faces and puts the surplus into cell depth.

Two things follow, and they are why this is examined.

The gain is real for honey supers. Thicker comb means the capping surface stands proud of the wooden frame, so an uncapping knife or plane takes the cappings cleanly in one pass without gouging the comb or riding on the top bar and bottom bar. Fewer frames means fewer frames to uncap and handle per pound of honey, less total midrib to build, and a modestly higher honey yield per box because less of the box volume is wood. Nine frames in a ten-frame super is the standard sideline practice; eight is used by some, and at eight the comb is thick enough that the outer combs may be built irregularly or joined to the box wall.

The gain does not transfer to foundation, and this is the half of the proposition that is false. Bees need an accurate reference plane to build straight comb. Drawn comb supplies that reference: the existing comb faces on either side define exactly where the new comb must go, and the bees build parallel to them. A sheet of foundation spaced 1 5/8 inches from its neighbors gives the bees a reference at the midrib but a great deal of unallocated space on either side, and what they do with that space is build where it suits them - waving off the foundation plane, building bridges from one frame to the next, and drawing comb on the face of the adjacent foundation sheet rather than on their own. The result is cross-built comb that cannot be separated without destroying it.

The rule, therefore: **draw comb at the full frame complement, then reduce spacing only afterward.** Ten frames in a ten-frame super to draw; nine thereafter. The same logic applies to the brood nest: full complement to draw, and many beekeepers keep brood boxes at ten permanently because thicker brood comb offers no benefit and slightly reduces the number of cells available to the queen.

When you do run nine, the frames must be *evenly* spaced, which does not happen by hand. Nine frames pushed together with a two-inch gap at one wall will give you eight normal combs and one monstrous slab welded to the box side. Use a frame spacer tool, metal or plastic spacer rails, or a follower board that fixes the position. Check spacing every time the box is closed; bees will not correct your arithmetic.

6.6 Floors, Covers and the Management of Air and Water

6.6.1 Screened versus solid bottom boards

A screened bottom board replaces the solid floor with 8-mesh hardware cloth over an open frame, usually with a removable tray or sticky board beneath. Understanding what it does and does not do is

one of the most consequential pieces of equipment knowledge in the region, because the error here kills colonies.

What it does well is **monitoring**. Mites that fall off bees naturally, or are groomed off, drop through the mesh where they cannot climb back up, and land on a board you can count. A 24- or 72-hour natural mite drop, divided by the days, gives you a trend line and a cheap early warning between alcohol washes. It also provides **ventilation**, which in a southeastern summer is a genuine benefit: it reduces the fanning workforce, reduces bearding, and helps a colony hold brood nest temperature on a 98-degree afternoon.

What it does only marginally is **control mites**. The classic southeastern field test - Ellis, Delaplane and Hood, *American Bee Journal* 141 (2001) - found that screen floors did not produce a meaningful reduction in mite population. A later meta-analysis pooling seven studies and 145 colonies (Liu and colleagues, *Insects* 11:624, 2020) did find a statistically significant effect once the trials were combined, but positioned screened floors as one item in a mite-control toolkit rather than a treatment. The honest master-level statement is: screened bottom boards produce at most a small reduction in mite population, the effect is not large enough to hold a colony below threshold, and their principal value is monitoring and ventilation.

The consequential error is the belief that a screened bottom board *is* mite control. That belief costs colonies every autumn: the beekeeper feels they have done something about mites, skips a treatment, and the colony collapses in October with a mite-vectored virus load it never signals until the population crashes. Note in passing that a screened floor is also not a small hive beetle barrier - adult beetles pass 8-mesh screen freely, and the mesh is sized to pass mites, not to block a 5 mm beetle. Some beetle trap designs use the space beneath a screened floor to hold oil, which is a different thing from the screen excluding beetles.

Solid bottom boards remain the better choice in some situations: a very weak colony or a small nuc that struggles to hold heat and control its own airspace, colonies that must be moved and sealed, and winter in windy exposed sites where the open floor turns the hive into a chimney. Many beekeepers in the region run screened floors with the tray inserted through winter, which is a reasonable compromise: closed floor when heat retention matters, open floor and monitoring capability the rest of the year.

6.6.2 The slatted rack

A slatted rack is a shallow frame of wooden slats, usually with a solid board across the front portion, placed between the bottom board and the lowest brood box. The slats run beneath and parallel to the frames, adding roughly two inches of vertical space under the brood nest.

The clustering-space function follows directly from geometry, and the draft-buffering claim is widely reported by beekeepers. It creates a **clustering space** below the combs where bees can hang in hot weather instead of bearding on the hive front - useful in a southeastern summer, and it keeps returning foragers out of the brood area. And it **buffers the brood nest from draft**: with a slatted rack, air entering the entrance does not blow directly across the face of the lowest combs. Beekeepers report that the

queen then lays to the bottom bar of the lower frames rather than leaving the bottom two inches of comb empty, but this has not been tested in controlled trials.

The third claimed function, **swarm reduction** through relief of congestion beneath the brood nest, rests essentially on beekeeper observation. It is plausible - congestion in the brood nest is a real swarm trigger and a rack does add space - but it has not been demonstrated in controlled trials, and a candidate should present it as such. Being able to say "this benefit follows from geometry and this one is widely believed but not demonstrated" is itself part of what master-level assessment measures.

6.6.3 Inner covers and the physics of winter moisture

This is the single most misunderstood piece of overwintering physics, and the exam targets the misunderstanding directly.

A clustered colony metabolizes honey. The oxidation of sugar yields carbon dioxide and water: metabolizing roughly a pound of honey releases a substantial volume of water vapor into the hive, and a wintering colony in the southeastern US may consume 20 to 40 pounds of stores across the season. That vapor rises with the warm air off the cluster. It condenses wherever it meets a surface below the dew point - and the coldest surface in a sealed hive is the underside of the cover, because that is the boundary against outdoor air with nothing between.

Condensate on the inner cover then drips back down onto the cluster. **Cold air does not kill a wintering colony; cold water does.** A dry colony survives temperatures far below anything the southeastern US produces. A wet colony chills, the cluster loses its ability to hold temperature, and fungal problems follow. This is why the correct account is that vapor must be allowed to escape, or the top must be kept warm enough that condensation does not form there.

Three interventions follow, and they are not alternatives so much as complements:

- **An upper vent.** A notched inner cover, a small upper entrance, or a shim with a gap lets warm moist air leave at the top. It also gives foragers a route when the bottom entrance is blocked, and it lets drones out above an excluder. The objection that an upper vent wastes heat is largely misplaced: the colony is not heating the hive, it is heating the cluster.
- **A forward tilt.** Two degrees of tilt toward the entrance means condensate that does form runs out rather than pooling on the bottom board. This is worth doing year-round in the region, because it also drains rain.
- **Insulation above the cluster.** This is the counterintuitive one. Insulating the top *reduces* condensation on the bees, because it raises the temperature of the top surface above the dew point so vapor does not condense there. Where condensation then occurs is on the outer walls, lower down, away from the cluster, where it runs down and out. A common configuration is a rigid foam board or a quilt box of absorbent material above the inner cover. The claim that insulating above the cluster *increases* condensation onto the bees inverts the physics and is a standard distractor.

Do not dismiss this as a northern problem. Mild wet winters in the southeastern US generate abundant vapor - the colony is often still rearing brood, so metabolic rate and therefore water production stay

high - and a tightly sealed hive with a cold inner cover will drip in a coastal plain January just as it will in a northern one. Mitchell (*International Journal of Biometeorology*, 2016) quantifies how poorly a thin-walled wooden hive retains heat compared with a tree cavity, which is why top insulation helps, and he argues that the higher humidity of tree nests is beneficial; the practical point is that the thin-walled wooden box is a far worse thermal enclosure than a tree cavity, and moisture management is where that difference bites.

6.6.4 Entrance reducers, mouse guards and robbing screens

An **entrance reducer** is a notched wooden cleat that narrows the entrance to a few inches or to a single small opening. Its function is defensive: it reduces the perimeter that guard bees must patrol, so a small colony can defend against robbers and beetles at a fraction of the cost. Use it on every nuc, every newly hived swarm, every recently requeened or otherwise weakened colony, and on everything during a dearth. Remove it, or open it to the wide notch, when a strong colony needs the traffic capacity during a flow - a reduced entrance on a strong colony during the main flow is a traffic jam that costs foraging time and causes bearding.

A **robbing screen** is a different device and solves a different problem. It is a screened box over the entrance whose actual opening is displaced - usually to the top or side of the screen - so that the colony's own bees learn the indirect route within a day while robbers, which are thought to orient to the scent plume coming through the screen, hammer the screen face and never find the way in. The device is widely reported to work, although the mechanism - residents learning the displaced opening while robbers follow the colony odor - has not been tested experimentally. Robbing screens are more effective than reducers once robbing has actually started; a reducer alone on a colony already being robbed often just concentrates the fight.

In the southeastern US, robbing pressure is a summer-dearth phenomenon as much as a fall one: the gap between the spring flow and the fall flow is when weak colonies get cleaned out. Robbing is also how American foulbrood and Varroa move between colonies within an apiary, so robbing control is disease control.

Mouse guards - a strip of hardware cloth or metal with holes too small for a mouse - matter less in the region than further north but are still worth fitting on colonies in barns, sheds and overgrown yards. A more important regional equivalent is a **skunk defense**: skunks scratch at the entrance and eat bees as they emerge, night after night, and the classic evidence is a colony that has become unusually defensive plus scratch marks and muddy patches at the entrance. A tall hive stand, so that the skunk must expose its belly to reach the entrance, is the standard remedy.

6.7 Queen Excluders

6.7.1 The dimensions, and why the tolerance matters

A queen excluder passes workers and blocks the queen by presenting a gap narrower than her thorax. The functional gap in a standard excluder is approximately **4.1 to 4.4 millimeters** - about 0.16 to 0.17

inch. A worker's thorax passes; the wider thorax of a laying queen does not, and neither does the thorax of most drones.

The narrowness of that window explains everything that goes wrong with excluders. A tolerance of a few tenths of a millimeter means:

- A **distorted, bent or corroded** excluder can pass a queen. Wire excluders bent by a hive tool, or plastic excluders that have warped in the sun or been stacked under weight, open a slot somewhere. Inspect excluders before use and hold them up to the light; a slot that is visibly wider than its neighbors is a queen-sized hole.
- **Poorly manufactured** excluders pass queens. Cheap plastic excluders with inconsistent slot width are a recurring complaint, and the failure mode is a super full of brood.
- **Small or virgin queens sometimes pass a sound excluder.** A virgin's thorax is not narrower than a mated queen's, but her abdomen is, and she is far more agile; small queens from poor rearing conditions can also get through. So "there is brood above the excluder" does not prove the excluder is faulty - it may prove the queen was small, or that the colony superseded and a virgin walked up before mating.
- **Drones cannot get down.** Drones that hatch above an excluder, or workers-turned-drone-escort, cannot pass back through it. They accumulate at the excluder and die there, and a mat of dead drones plugs the slots and begins to block worker traffic as well. The remedies are an upper entrance during the flow, so drones can leave and return by their own route, or periodic removal of the excluder for a day.

Do not confuse the excluder gap with bee space. A 6.5 mm gap - bee space - would pass a queen without hesitation; slot *length* has nothing to do with it. And a 2.5 mm gap would exclude workers as well, which is the basis of the distractor claiming that an excluder passes only young workers.

6.7.2 The arguments about excluders

The craft genuinely disagrees here, and a master-level answer should present both sides with their mechanisms rather than picking a team.

The case for using one is bookkeeping and product quality. Brood in supers means dark travel-stained comb, pollen in the extractor, and either a delayed harvest while you wait for brood to emerge or a set of frames you cannot extract. It also means you know where the queen is when you pull supers, so you are not carrying her to the honey house. For anyone selling comb honey or cut comb, brood in a section is a total loss of that section. And in a two-queen or cell-building setup, an excluder is not optional - it is a structural component.

The case against - the "honey excluder" argument - is that any barrier imposes a cost on traffic. Workers loaded with nectar must squeeze through a slot, and many beekeepers report that bees are slow to cross an excluder to begin storing in a fresh super, particularly if the super is undrawn foundation. The one controlled study (Bundschuh and colleagues, 2024) found no significant difference in colony dynamics between hives managed with and without excluders, and a yield penalty has not been demonstrated. The reported consequence is a delayed start to super use. The counter-arguments within

the craft are that the effect largely disappears if you (a) use a wood-bound wire excluder rather than a stamped metal sheet, which has a much higher open area and no sharp edges, (b) give the colony drawn comb rather than foundation above the excluder, and (c) bait the super by moving one frame of open nectar up above the excluder to draw the bees through.

A defensible middle position, common among sideliners in the region: use excluders on colonies producing extracted honey where brood-free supers matter, use wood-bound wire, always bait the first super, provide an upper entrance, and omit the excluder on colonies you are running foundationless or on colonies you know to be poor at moving up. Omitting the excluder and simply managing the brood nest so the queen does not go up - by keeping open comb available below - also works, and is what many commercial operations do.

6.8 Comb: The Most Valuable Asset in the Shed

6.8.1 What comb costs

Ask what a box of drawn comb is worth and the answer is not the price of the foundation. Wax is secreted by workers from glands on the ventral abdomen, and secretion is metabolically expensive: the classical figure, quoted in the standard texts, is on the order of **6 to 8 pounds of honey consumed per pound of beeswax produced**, with experimental estimates varying considerably with temperature, forage and colony condition. Take a deep frame at roughly 100 grams of wax and a ten-frame deep at roughly a kilogram, and the direct cost of drawing one deep box of comb lands somewhere in the region of 13 to 18 pounds of honey.

The direct cost understates the real one. Wax-secreting bees are bees not foraging. Comb-building happens during a flow, and the flow is short. A colony given a box of foundation at the start of the main flow spends the first part of that flow building rather than storing, and the honey it does store goes partly into the new comb rather than into your extractor. The same colony given drawn comb starts filling on day one. In the southeastern US, where the spring flow can be over in three to five weeks, that difference is most of the crop.

So: a box of drawn comb is worth roughly a box of honey, plus the time it cannot be replaced in. Losing comb is losing capital. This is why wax moth and small hive beetle damage in storage is an economic disaster rather than a nuisance, why a flooded apiary is worse than a windblown one, and why comb should be stored with the same seriousness as the honey crop.

6.8.2 Storing comb without losing it

Drawn comb in storage is defenseless - there are no bees to patrol it - and two organisms will find it. Greater wax moth larvae tunnel through comb, eating the cocoon and pollen debris in brood comb in preference to clean honey comb, and reduce a super to webbing within weeks in warm weather. Small hive beetle larvae will also develop in stored comb containing honey or pollen, with the added insult that their slime ferments the honey and renders the comb unusable even where they have not eaten it.

The reliable methods:

- **Freezing.** Twenty-four to forty-eight hours at 0 degrees F kills all life stages of wax moth and small hive beetle, including eggs. Freeze comb as it comes off, then store it protected.
- **Light and air.** Wax moth avoids light and moving air. Stacking supers crosswise in an open, bright, airy shed - or storing them in stacks with a queen excluder as the bottom layer to exclude mice, spaced so light passes - is the traditional method and works well on honey comb, less reliably on dark brood comb.
- **Bt.** *Bacillus thuringiensis* subsp. *aizawai*-based products sold for wax moth control on stored comb (confirm the product is currently registered in your state) are sprayed on comb before storage and remain effective through a season. This is a biological larvicide specific to lepidopteran larvae; it does not control small hive beetle.
- **Not acceptable: para-dichlorobenzene (PDB) or naphthalene.** PDB products are registered for stored comb, but PDB is absorbed into wax and carries into honey, so it is not acceptable for comb that will be used in food production - the position the examination takes. **Naphthalene - ordinary mothballs - is never acceptable.** It contaminates wax and honey and is not labeled for the use.
- **Do not use sulfur, and do not use anything unlabeled.** Comb is a food-contact surface.

Freezing plus dry, airy storage is the best combination for a sideline operation in the region. The one thing that does not work is stacking supers of brood comb in a dark warm shed in June and hoping.

6.8.3 Comb rotation

Comb is also a sink, and this is the second half of the comb story that separates a master-level answer from a competent one.

Three things accumulate in brood comb. **Cocoons**: each larva spins a cocoon and each emergence leaves a layer behind, so cell volume shrinks slightly and cell walls thicken over generations. Very old comb is nearly black, and while the effect on emerging bee size is modest and contested, it is real. **Pathogen load**: *Paenibacillus larvae* spores persist in comb for decades, chalkbrood spores for years, and *Vairimorpha* (*Nosema*) spores contaminate comb surfaces. **Chemical residue**: lipophilic miticides partition into wax and stay there. Fluvalinate and coumaphos are the historic offenders; amitraz is less persistent in wax but its degradation products are detectable, and agricultural pesticides arrive in pollen and are stored in the comb.

The response is planned comb rotation. The common recommendation is to **replace about 20 percent of brood comb per year, giving each comb roughly a five-year service life**; more aggressive programs run 33 percent a year on a three-year cycle, and some operations that have had disease problems or heavy chemical exposure go faster. The exact number matters less than having a number and a marking system - a year mark on the top bar in paint or a dated thumbtack - so that rotation actually happens rather than being intended.

The mechanics are straightforward if you plan for them. The oldest combs are at the outside of the brood nest and at the bottom of the stack. In spring, move the darkest combs to the outside positions where the queen will not lay in them, let them be backfilled with honey, then remove them at harvest

and melt them. Replace with foundation or foundationless frames placed at the edge of the brood nest during a flow, never in the middle of the nest in a dearth. Colonies being requeened, split, or hived as swarms are all natural opportunities to introduce new comb.

Two cautions. First, comb rotation is not free - each comb you cull must be redrawn at the cost described above, so a rotation program is a real annual expense that has to be scheduled into a flow. Second, do not rotate everything at once. A colony stripped of drawn comb and given a full set of foundation in a dearth will not build, will consume stores, and may abscond.

6.9 Equipment Sanitation: What Can Be Salvaged and What Cannot

The governing question is always: is the pathogen a spore-former, and is it in the wax or on the wood?

American foulbrood. *Paenibacillus larvae* spores remain viable for decades - thirty-five years and beyond is the figure usually quoted - and are not killed by antibiotics, by ordinary scorching of comb, or by wax rendering at normal temperatures. Comb and frames from an AFB colony **cannot be salvaged** by any method available to a beekeeper. The standard disposal is burning the bees, frames and comb in a pit and burying the ashes, which remains required or strongly directed in most jurisdictions. Hive bodies, bottom boards, covers and metal parts can in many jurisdictions be salvaged by **scorching**: scrape clean, then flame the interior surfaces with a torch until the wood is uniformly charred; a light browning is not enough, because the surface has not reached the temperature that destroys spores. Commercial **gamma irradiation** sterilizes whole hives including comb where a facility is available, and is the method that makes equipment salvage economically sensible at scale. Follow your state apiary inspection service's direction; this is one of the areas where the law, not the beekeeper, decides.

As Chapter 10 explains in detail, oxytetracycline, tylosin and lincomycin have required veterinary oversight since 1 January 2017, via a Veterinary Feed Directive for in-feed products or a prescription for water-soluble ones, and that they suppress the vegetative stage only. They mask AFB; they do not cure it, and the spores in the comb are untouched. Equipment sanitation, not medication, is what breaks the cycle.

European foulbrood. *Melissococcus plutonius* does not form true spores, though it persists on comb. EFB colonies are often managed by requeening and a break in brood rearing, and comb is sometimes salvageable, but heavily affected brood comb is best culled. Where the diagnosis is uncertain, treat it as AFB until a laboratory says otherwise.

Chalkbrood. *Ascosphaera apis* spores persist in comb for years. Chalkbrood is primarily a stress and moisture disease; the response is requeening to a more hygienic line, improved ventilation, a drier site, and culling the worst comb rather than any treatment.

Nosema/Vairimorpha. Spores on comb surfaces are killed by acetic acid fumigation (concentrated acetic acid over stacked supers in a sealed stack, a European practice, using proper protective equipment) or by heat. Ordinary comb rotation handles it adequately in most operations.

Small hive beetle slime. Comb that has been slimed is generally not salvageable as comb; the fermented mass is unattractive to bees, and the wax is not normally rendered either, because slimed comb is

unsuitable, difficult and inefficient to render. It is destroyed (Chapter 13). Wooden boxes wash and scrape clean.

Wax moth. Damage is mechanical. Comb reduced to webbing is a total loss; lightly tunneled comb is often repaired by a strong colony. Frames and boxes are reusable after cleaning.

Pesticide kill. Where a colony has been killed by a pesticide event, the contaminated material is in the pollen and the wax. Removing and destroying the stored pollen frames is the first step; heavily contaminated brood comb should be culled.

Two general principles close this section. First, **wax rendering is not sterilization.** Melting comb at normal rendering temperatures does not destroy AFB spores and does not remove lipophilic residues - it concentrates them, because the residue follows the wax. Second, **plastic frames and boxes are chemically resistant but not immune**: they can be washed with a bleach solution or scorched carefully, but plastic that has held AFB comb should be treated with the same suspicion as wood and disposed of if your inspection service says so.

6.10 Extracting Equipment

The exam treats extraction equipment as an equipment topic rather than a honey topic, and the distinction that gets asked is radial versus tangential.

A **tangential** extractor holds each frame with one face outward, parallel to the basket wall. Centrifugal force throws honey out of the cells on the outward-facing side only. The frames must therefore be **reversed** - turned around halfway through the cycle - to empty the second face. Small hand-cranked two- and four-frame extractors are usually tangential.

A **radial** extractor holds frames like the spokes of a wheel, top bar outward, with the comb plane in line with the radius. Both faces empty at once and **no reversing is required**. Radial extractors are usually larger, from nine frames up to commercial machines holding dozens.

The reason radial extraction works at all is a small anatomical fact: comb cells are not horizontal. They tilt upward from the midrib to the mouth by roughly 9 to 14 degrees, which is what keeps unripe nectar in the cell. With the top bar outward, the force acts along the plane of the comb, toward the top bar, nearly at right angles to the cells. Because the cells tilt upward from the midrib, part of that force points toward the mouth of every cell on both faces, so both sides empty without reversing, though more slowly and at higher speed than in a tangential machine.

The practical comparison:

	Radial	Tangential
Frame orientation	Like spokes, top bar outward	One face parallel to basket wall
Reversing	Not required	Required, halfway

	Radial	Tangential
Speed per frame	Faster; no handling mid-cycle	Slower; every frame handled twice
Gentleness on comb	Higher stress on the midrib	Can be gentler if run slowly
Typical scale	Nine frames and up	Two to six frames

Three operating points apply to both. **Warm the honey**: honey viscosity falls sharply with temperature, and frames extracted straight from a cool hive or an air-conditioned honey house will not empty. Holding supers at about 90 to 95 degrees F overnight - a hot room, not a hot box that melts wax - makes an enormous difference and reduces the speed needed. **Increase speed gradually**: bring the machine up slowly, let honey come off, then increase. A cold start at full speed is how midribs blow out. **Match the method to the comb**: old dark comb is reinforced by generations of cocoons and is structurally much stronger than new pale comb; new comb, foundationless comb, and any comb in a frame without wire or plastic support should be extracted tangentially, slowly, or not at all. The frame that blows out is always the new one, and blown-out comb is capital destroyed.

6.11 The Hive Scale as an Instrument

A hive scale placed under a colony and recording continuously produces a time series of net colony mass. That is all it measures, and its analytical power comes entirely from interpretation of the shape of the curve.

What the curve shows that no single inspection can:

- **Flow onset and end.** A colony gaining weight every day is on a flow. The slope of the gain is the flow's intensity; the inflection where the slope goes to zero is the day the flow ended. Nothing you see inside a hive tells you that within a day or two. For a beekeeper building a bloom calendar for a specific site in the southeastern US - where the spring flow may run from a tulip poplar and blackberry sequence into a summer dearth and then a fall aster and goldenrod flow, and where the dates shift by a week or more between the coastal plain, the piedmont and the mountains - a scale is the most efficient instrument available.
- **Dearth.** A flat or slowly declining curve during the day, with continued overnight loss, is dearth. The scale tells you the day feeding becomes necessary, which is usually earlier than a beekeeper guesses.
- **Swarm departure.** A sudden loss of several pounds within a period of minutes, in mid-morning to early afternoon, on a warm day with no visit logged, is almost certainly a swarm leaving. Absconding or the beekeeper's own manipulation, such as pulling a super or taking a split, can produce a similar step, so check the management log.
- **Robbing.** A rapid, asymmetric gain - much faster than any flow could produce, sometimes several pounds in a couple of hours - means your colony is robbing a neighbor. The corresponding hive on the losing end shows a matching rapid loss.

- **Overnight consumption.** The nightly decrement quantifies how much the colony is eating, which in winter is the single most useful number for deciding whether to feed and when the colony will run out.
- **Foraging rhythm.** The daily sawtooth - a morning dip as the foraging force departs, a build through the day, a step up at evening return - lets you see the size and timing of the foraging effort. The morning dip is roughly the mass of the departing foragers.
- **Nectar ripening.** Weight loss overnight during a strong flow, in excess of consumption, is water being driven off as nectar is cured.

What a scale does **not** do is equally examinable. It does not detect Varroa - there is no weight signature of mite infestation distinguishable from ordinary colony decline. It does not measure adult population directly; the scale reads combined mass of bees, brood, comb, stores and woodenware, and cannot separate them. And it does not replace inspection: queenlessness, foulbrood, laying workers, queen cells and chalkbrood produce no distinctive weight signature. Meikle and Holst's review (*Apidologie* 46, 2015) is the standard reference on what continuous weight monitoring can and cannot resolve.

The practical setup: one scale per apiary on a representative colony, tared with known woodenware, recorded at least hourly, with temperature logged alongside so that you can separate genuine mass change from rain on the lid and evaporation of dew. Two scales per apiary - one on a strong colony, one on an average one - is better, because it separates colony-specific events from apiary-wide flow events.

6.12 Siting an Apiary in the Southeastern US

Apiary siting is where equipment knowledge meets regional biology. The following are the considerations a master-level answer should be able to produce and, more importantly, justify.

6.12.1 Sun and shade

Morning sun with some afternoon shade is the regional formula, and each half has a reason.

Morning sun warms the hive early and the bees fly earlier, which matters because many of the region's important nectar sources yield best in the morning and because an early start lengthens the foraging day. Sun on the entrance also dries the front of the hive and appears to reduce the pathogen load associated with chronically damp equipment.

Afternoon shade addresses heat. A hive in full sun at 98 degrees F with high humidity commits a large fraction of its workforce to fanning and water-carrying rather than foraging, beards heavily on the front, and risks comb softening in supers. Light afternoon shade - a high deciduous canopy, the east side of a treeline, shade cloth on a frame - removes most of that load without darkening the site.

What to avoid is **full-day deep shade**, and the reason is specific and regional: shaded sites stay damp, and soil moisture is the controlling variable for small hive beetle pupation. This is developed below, but note it here as the mechanism behind the siting rule.

6.12.2 Drainage and flood level

Site hives on **well-drained ground above flood level**. In the coastal plain and in river bottoms, the relevant flood is not the annual high water but the 10- or 25-year event, and it is worth knowing where that line is before you put twenty colonies below it.

Standing water kills colonies. Bees are not drowned in the box, usually; what happens is that water reaches the bottom board, the colony is chilled, the comb is fouled with silt, brood dies, and the surviving bees abscond or dwindle. In a tropical system the wind may not take a single colony while the flood that follows takes all of them. A great many colonies lost to named storms in the region were lost to standing water two days after the wind stopped.

Hive stands are therefore not optional in the region. A stand of 16 to 24 inches (18 or more where skunks are active) raises equipment above minor flooding and above the damp layer near the ground, improves airflow beneath the hive, reduces back strain when lifting supers, makes skunk predation costly, and - critically - provides the defined path that ant control depends on.

6.12.3 Air drainage

Cold air is denser than warm air and flows downhill at night, pooling in hollows, at the base of slopes, and behind obstructions. A colony in a frost pocket experiences colder nights, later spring build-up and more moisture than one fifty feet up the slope. Site for **good air drainage**: a gentle slope, a bench above a hollow, or the upper side of a field, not the bottom of a draw. The same slope that drains cold air usually also drains water, so the two considerations point the same way.

The exception is wind exposure: a ridge top has excellent air drainage and terrible wind exposure. The compromise is upper-slope, sheltered on the prevailing winter-wind side.

6.12.4 Vehicle access

Supers must be carried. A ten-frame medium of capped honey is 50 to 60 pounds, and an apiary of twenty colonies produces a load no one carries across a field twice. Access must be adequate **in wet conditions**, which is the constraint that catches people: a track that is fine in May is a rut in a wet February, and the colonies still need feeding in February.

Judge access on the worst day, not the best. Consider also that if you cannot get a truck in, you cannot get bees *out* - and evacuating colonies ahead of a flood or a pesticide application is a real scenario in the region.

6.12.5 A water source, established before the bees find one

A colony uses water for brood-food dilution and for evaporative cooling, and in a southeastern summer the cooling demand is large - a strong colony may collect a quart (about a liter) or more a day. Bees forage for water like any other resource and show strong fidelity to a source once established: scouts find it, recruit to it, and the colony returns to it for the season.

The management consequence is that **you must establish the water source before the bees establish one for you**, because the one they choose will be the neighbor's swimming pool, the dog's bowl, the

stock tank, or the condensate drip from an air conditioner - and once they have learned it, moving them off it is very difficult. Put water in the apiary before the colonies arrive, or at the latest the same day.

What works: a shallow trough, tub or bucket with floats - corks, sticks, gravel, a board - so bees can drink without drowning; a slow drip onto a sloped board; a small pond edge. Bees prefer water that smells of something over distilled purity, which is why they like pool water and stock tanks; a little salt or a few leaves left to steep improves the attractiveness of your source and helps win the competition. Keep it filled without fail through the dry months. A source that runs dry in July teaches the colony to look elsewhere, and you will not get them back.

6.12.6 Wind and storm protection

Prevailing winter wind on the entrance chills the hive and costs stores. A windbreak - a treeline, a building, a fence, or a slope - on the north and west sides of the yard is worth having. Face entrances away from the prevailing winter wind; southeast-facing entrances are the regional default because they get morning sun and turn their backs on winter northwesterlies.

Also consider **falling limbs**. A yard directly under mature pines or large hardwoods is convenient shade and a hazard in every wind event. Clear obviously dead limbs and dead trees before you site the yard, not after.

6.12.7 Neighbors, sight lines and flyways

Separation from neighbors, public paths, livestock and tethered animals is a legal and social requirement as much as a biological one. Tethered or penned animals are the specific hazard: an animal that cannot leave the area of a disturbed colony can be stung to death, and that is the scenario behind a great many nuisance actions.

Two devices manage the flyway. A **flyway barrier** - a solid fence, hedge or screen at least six feet high placed close to the hive fronts - forces departing bees to climb steeply, so they cross a neighbor's property well above head height rather than at face level. Most regional ordinances and best-management-practice documents specify this, often with a required setback from the property line as an alternative. A **sight-line screen** serves a different purpose: it keeps the hives from being visible, and hives that cannot be seen generate far fewer complaints than hives that can, independent of whether anyone has actually been stung. Vandalism and theft follow visibility too.

Colony density is part of the same calculation. An apiary of forty colonies in a suburban back lot is a different proposition from four, both in forage competition and in the magnitude of any incident. Many sideline operations in the region run yards of 20 to 30 colonies on rural sites and far fewer in residential ones.

6.12.8 Forage and pesticide exposure at the landscape scale

Assess the site over the colony's actual foraging range - two to three miles, which is on the order of 8,000 to 18,000 acres - not the property boundary. What matters at that scale is the sequence of bloom (whether there is anything between the spring flow and the fall flow), the presence of large monoculture blocks that produce a strong brief flow and nothing after, the presence of row-crop

acreage and the pesticide regime that goes with it, and whether mosquito abatement spraying is done in the area and on what schedule.

The practical steps are to walk or map the radius, identify the dearth periods, and - this is the part beekeepers skip - introduce yourself to the neighboring landowners and to the applicator or co-op that sprays the adjoining ground, and register the apiary on the state's driftwatch-style sensitive-site registry where one exists. A phone call the day before an application is worth more than any equipment.

6.12.9 Fire ants

Imported fire ants (*Solenopsis invicta*) are a regional constant. They exploit weak colonies, nucs, newly hived swarms, and any colony whose defensive capacity is reduced; they will take brood and stored food, and they will kill a small colony outright. They are also a hazard to the beekeeper standing in the yard.

The control strategy is built on the hive stand, and the logic is simple: **without a stand, the hive sits in the ants' foraging substrate and no barrier is possible.** With a stand, ants must follow a defined path - the legs - and a defined path can be treated.

- **Set the stand legs in containers of oil**, or coat them with an automotive grease or a sticky barrier. Ants will not cross either. Oil cups need topping up and need covers to keep rain from floating the oil out.
- **Clear vegetation from around and beneath the stand.** A blade of grass touching the hive is a bridge, and a barrier with a bridge around it is no barrier. This is the failure mode that defeats most oil cups.
- **Keep colonies strong.** A full-strength colony repels fire ants adequately on its own. Ant problems are almost always secondary to a colony problem - queenlessness, disease, a failed split - and the ants are the symptom.
- **Bait at a distance.** Where baiting is used, apply an approved fire ant bait to mounds **away from the hives**, following the label exactly, so that foraging bees do not contact the bait and hive products are not contaminated. Never broadcast bait through an apiary.

6.12.10 Bears

Black bears are a regional problem in the southern Appalachian mountains, in the larger river swamps, and in an expanding set of piedmont counties. A bear that finds an apiary destroys it and returns.

Electric fencing is the only reliable protection. The specification that matters is voltage at the fence, grounding, and geometry. Extension guidance gives a minimum of about 3,000 volts at the wire for deterrence (UConn Extension); the North Carolina Wildlife Resources Commission recommends 4,000 to 5,000 volts, the better target for southeastern black bears. Run wire strands at heights on the order of 4, 16, 26 and 36 inches so that a bear cannot go under, between or over. Grounding is where most fences fail: a ground rod driven several feet into moist soil, and vegetation kept off the wires so the fence is not shorted to earth. Test the fence with a voltage tester on a schedule; a fence that reads zero is a fence that is not there. Baiting the fence - a strip of bacon or foil smeared with something attractive clipped to the hot wire - teaches the bear with its nose, which is far more effective than a shock to the fur.

The other rule is that fencing must go up **before** the bear finds the yard, not after. A bear that has fed at an apiary will work much harder to get back in.

6.12.11 Shade, soil moisture and small hive beetle

This is the interaction that ties the siting section together and is exactly the kind of mechanism-level connection a master-level exam probes.

Small hive beetle has a soil-dependent life stage. Wandering larvae leave the hive, enter the soil, and pupate there. Two studies define what determines their success. Ellis, Hepburn, Luckman and Elzen (*Environmental Entomology* 33, 2004) tested soil type, moisture and density: **moisture was overwhelmingly the dominant factor** - about 91.5 percent of larvae emerged as adults from wet soil treatments and essentially none emerged from dry soil - while soil type itself had comparatively minor effect, and density effects were inconsistent. Meikle and Diaz (*Journal of Insect Science* 12, 2012) showed that **depth** matters as well: larvae given 4 to 8 cm of soil pupated at very high rates, while at 1 cm almost none succeeded and at 0 to 0.5 cm none did.

Put those together with a siting decision and the chain is direct. A heavily shaded site keeps the soil surface damp. Damp soil permits pupation. Loose, friable, well-worked soil of any texture that stays damp and offers several centimeters of depth is ideal beetle nursery. So a moist, deeply shaded yard is one that recycles its own beetle population efficiently, while a site with sun on the ground for part of the day and soil that dries between rains breaks a large fraction of the beetle life cycle for free.

That does not mean no shade. It means **partial shade, not deep shade**; sun reaching the ground, not just the hive lids; and it explains why the standard regional advice pairs “afternoon shade” with “avoid dense woods.” It also explains why beetle pressure is often worst in irrigated, mulched or heavily vegetated yards, and why pressure differs so much between yards a mile apart.

The equipment corollaries follow the same logic. Strong colonies patrol comb and confine beetles; a weak colony or a box of unattended comb is where beetles breed. Do not leave supers of comb standing in the yard. Do not leave a dead-out unattended. Keep colonies compact - do not super a weak colony into a volume it cannot patrol. And handle the equipment gently, because crushed bees and broken comb are the oviposition sites beetles prefer.

6.13 Storms, Floods and Recovery

Preparing an apiary for a severe tropical storm is a specific regional competence and a legitimate examination topic. The three hazards are **wind, falling limbs and flooding**, in that order of arrival and in reverse order of total damage.

Before the storm:

- **Strap each hive.** A ratchet strap around the whole stack, from bottom board to telescoping cover, prevents the boxes from separating. Boxes that separate in wind lose their combs entirely - the combs fall, the honey runs, the colony is destroyed even if the bees survive. Strap the hive **to its stand**, and anchor the stand to the ground with earth anchors or stakes where the site permits.

- **Reduce stack height.** A tall stack is a lever arm; the force at the base rises with height, and a four-high stack goes over in wind a two-high stack survives. Pull supers where practical, or consolidate.
- **Move colonies off flood-prone low ground**, if you have anywhere to move them and time to do it. This is the step that saves the most colonies and the one most often skipped, because it is the most work. Note again the access constraint: if the track is already soft, moving becomes impossible well before the storm arrives.
- **Weight the lids** where strapping is not possible - a concrete block is the minimum - and remove loose equipment, empty boxes and lightweight gear from the yard, since these become projectiles.
- **Clear dead limbs and trees** over the yard well in advance.

After the storm:

- **Access will be a problem.** Roads and tracks may be impassable for days, and chainsaw work may be necessary to reach a yard. Build that into the plan; a colony knocked over and left for a week is a colony robbed out.
- **Righting and reassembling** colonies promptly matters. Comb that has fallen should be removed; salvage what can be reframed, cull the rest.
- **Expect to feed.** A tropical system strips flowers and foliage over a wide area and ends the flow abruptly, sometimes weeks early. Colonies that had stores may have lost them in the disturbance, and colonies that were building on an autumn flow may be left with nothing. Post-storm feeding is routine, and post-storm robbing pressure is severe - feed carefully, with entrance reducers in place, and preferably inside the hive rather than open.
- **Standing water is the second wave.** Colonies that survived the wind are commonly lost in the days afterward to water that has not drained. Getting hives up onto blocks or pallets above the water line is the emergency action.
- **Document losses.** Photographs, colony counts and dates are what a federal disaster program (the USDA Emergency Assistance for Livestock, Honeybees and Farm-raised Fish program) will ask for, and the documentation has to be contemporaneous.

6.14 Numbers to Know Cold

Figure	Value	Why it is that value
Bee space	6 to 9 mm (1/4 to 3/8 inch)	The behavioral threshold: narrower gaps are propolized, wider gaps are filled with comb. It is a range, not a single value, and larger spaces below the frames are often tolerated.
Comb spacing, center to center	About 32 to 38 mm; Hoffman frames 1 3/8 inch (35 mm)	Comb thickness (22-25 mm for worker brood comb) plus one bee space between faces

Figure	Value	Why it is that value
Queen excluder gap	4.1 to 4.4 mm (about 0.16-0.17 inch)	Passes a worker's thorax, blocks the wider thorax of a laying queen and of most drones. The tolerance is tenths of a millimeter, which is why distortion defeats it.
Ten-frame body, outside	19 7/8 by 16 1/4 inches	Standard Langstroth footprint; interior 18 3/8 by 14 3/4
Eight-frame body, outside	19 7/8 by 14 inches	Same length, narrower; interior 12 1/2 inches wide
Box heights	Deep 9 5/8; medium 6 5/8; shallow 5 11/16 inches	Set so that frame plus bee space fills the box exactly
Frame depths	Deep 9 1/8; medium 6 1/4; shallow 5 3/8 inches; top bar 19 inches in all	Top bar length is constant, which is what makes frames interchangeable across manufacturers
Ten-frame deep of capped honey	About 80-90 lb	Roughly 7-8 lb per full deep frame plus the box
Ten-frame medium of capped honey	About 50-60 lb	Roughly 4.5-5 lb per full medium frame plus the box
Eight-frame medium of capped honey	About 40-48 lb	Eight tenths of the ten-frame figure
Nine-frame spacing in a ten-frame box	About 1 5/8 inches per frame	14 3/4 inches of interior width divided by nine
Comb thickness at ten- vs nine-frame spacing	About 7/8-1 inch vs about 1 1/4 inches	Bees hold bee space between faces and put the surplus width into cell depth
Cells per deep frame	About 3,400-3,500 per side, ~7,000 per frame	Basis of brood-area and wax-yield arithmetic
Wax per deep frame	On the order of 100 g	About 1 kg of wax per ten-frame deep box of comb
Honey cost of beeswax	Classically 6-8 lb honey per lb wax	Secretion is metabolically expensive; estimates vary with temperature and forage. A deep box of drawn comb costs roughly 13-18 lb of honey plus the foraging time lost
Comb rotation rate	About 20 percent of brood comb per year (5-year cycle); 33 percent (3-year) in aggressive programs	Balances residue and spore accumulation against the honey cost of redrawing comb
Pesticide residue in wax	98 percent of comb and foundation samples contaminated; fluvalinate to 204 ppm, coumaphos to	Lipophilic miticides partition into wax and persist; commercial foundation carries industry-wide residue history

Figure	Value	Why it is that value
	94 ppm (Mullin et al., 2010)	
Foundation cell size	Standard worker about 5.4 mm; natural worker 5.2-5.4 mm; drone 6.2-6.6 mm; “small cell” 4.9 mm	Small cell has not shown consistent mite reduction in controlled trials
Drone comb in a foundationless nest	Commonly 15-25 percent	Bees build more drone comb than foundation permits when given free choice
Honeycomb cell tilt	Roughly 9 to 14 degrees upward from midrib to mouth	Retains unripe nectar; also gives the in-plane force of a radial extractor a component toward the cell mouth on both faces
Freezing to kill wax moth and small hive beetle	24-48 hours at 0 degrees F	Kills all life stages including eggs
Small hive beetle pupation, wet vs dry soil	About 91.5 percent emergence from wet soil, essentially 0 percent from dry (Ellis et al., 2004)	Moisture, not soil type, is the controlling variable - the mechanism behind avoiding deep shade
Small hive beetle pupation depth	High success at 4-8 cm; almost none at 1 cm; none at 0-0.5 cm (Meikle & Diaz, 2012)	Larvae need soil depth, not just surface area
Paenibacillus larvae spore viability	35 years and beyond	Why AFB comb cannot be salvaged and why antibiotics mask rather than cure
Bear fence	At least about 3,000 volts at the wire (4,000-5,000 per NC Wildlife); strands at roughly 4, 16, 26, 36 inches	Prevents going under, between or over; grounding through a rod in moist soil is the usual failure point
Flyway barrier	Solid, at least 6 feet, close to the hive fronts	Forces departing bees above head height at the property line
Hive stand height	16-24 inches typical; 18+ where skunks are active	Above damp ground and minor flooding, allows ant barriers, defeats skunks, saves backs
Foraging radius for site assessment	2-3 miles (roughly 8,000-18,000 acres)	The scale at which forage sequence and pesticide exposure must be judged
Honey temperature for extraction	About 90-95 degrees F	Viscosity falls sharply with temperature; cold honey will not leave the cells

6.15 Common Misconceptions

Misconception: Bee space is a rough guideline - anything in the general neighborhood of a quarter inch will do. **Correction:** It is a narrow behavioral threshold, roughly 6 to 9 mm, with firm edges on both sides. Below it the bees usually propolize; above it they usually build comb. Between frames and between boxes there is little tolerance for “close enough.” That is precisely why the principle works as a manufacturing constraint and why warped or mismatched equipment produces comb problems in every hive it goes into.

Misconception: Top bee space and bottom bee space are just manufacturers’ preferences, so mixing boxes is fine. **Correction:** Mixing them in one stack creates a doubled gap at one junction, which the bees fill with burr comb, and a zero gap at another, which they propolize solid while crushing bees between the surfaces. You get both faults in the same hive. Pick a convention and hold to it across the whole operation.

Misconception: Burr comb between boxes just means the bees are busy. **Correction:** Burr comb is a diagnosis. It means the gap at that junction exceeds bee space - mixed conventions, a warped rim, a frame rest cut too deep, thin top bars, or too few frames in the box. Heavy propolis and crushed bees mean the opposite fault. Both are correctable, and scraping them off every visit without asking why is treating a symptom.

Misconception: Nine-frame spacing gives thicker, easier-to-uncap comb, so I will space my foundation at nine frames too and save the trouble later. **Correction:** The first half is right and the second is wrong. Bees draw deeper cells at wider spacing, but they need an accurate reference plane to build straight, and drawn comb supplies that where foundation does not. Foundation spaced wide gives wavy, cross-built comb welded frame to frame. Draw at the full frame complement, then reduce spacing afterward, using spacers or a follower so the frames stay evenly positioned.

Misconception: A screened bottom board controls Varroa. **Correction:** Controlled field trials found at most a modest reduction, and while a pooled meta-analysis found a statistically significant effect, it is nowhere near large enough to hold a colony below threshold. A screened floor is a monitoring aid - it lets you count natural mite fall - plus a genuine ventilation benefit in a southeastern summer. Believing it is a treatment is a recurring reason colonies are lost in autumn.

Misconception: A screened bottom board keeps small hive beetles out of the hive. **Correction:** Adult beetles pass 8-mesh screen freely; the mesh is sized so mites fall through, not to exclude a 5 mm beetle. Some trap designs use the space beneath a screened floor to hold oil, which is a trap working through the screen, not the screen working as a barrier.

Misconception: Cold air kills wintering colonies, so the hive should be sealed as tight as possible. **Correction:** Dry colonies survive cold far beyond anything the region produces. What kills them is water. Metabolic water vapor rises off the cluster and condenses on the coldest surface - normally the underside of the cover - and drips back onto the bees. Sealing the hive traps the vapor and guarantees the drip. Vapor must be able to leave, or the top must be kept warm enough that it does not condense there.

Misconception: Insulating above the cluster traps moisture and makes condensation onto the bees worse, so an open ventilated cover is better. **Correction:** This inverts the physics. Insulation above the cluster raises the temperature of that surface above the dew point, so vapor does not condense there at all; what condensation occurs happens lower on the outer walls, away from the bees, where it runs out. Insulated inner covers, foam boards and quilt boxes reduce the water reaching the cluster rather than increasing it.

Misconception: Winter moisture is a northern problem; in the mild southeastern winter it does not apply. **Correction:** If anything it applies more. Mild wet winters mean colonies keep rearing brood, so metabolic rate and water production stay high, and outdoor humidity is high to begin with. A tightly sealed hive with a cold inner cover will drip in a coastal plain January. A small upper vent, a slight forward tilt for drainage, or an insulated inner cover all address it cheaply.

Misconception: Brood in the honey supers proves the excluder is defective. **Correction:** It may - distorted, damaged or poorly made excluders do pass queens, and every excluder should be inspected before use. But a small queen from poor rearing conditions can pass a sound excluder, and a virgin queen produced by a supersedure below can pass one easily and then be mated and laying above it. Diagnose before you blame the hardware.

Misconception: An excluder is a queen excluder and nothing else passes or is blocked. **Correction:** It also blocks drones, which is a management problem rather than a benefit. Drones that emerge or are driven above an excluder cannot get back down; they die at the slots and their bodies plug the excluder, eventually obstructing worker traffic too. Provide an upper entrance during the flow, or lift the excluder periodically.

Misconception: A slatted rack reduces swarming. **Correction:** Its clustering-space function follows from geometry, and beekeepers report that it gives bees a place to cluster off the brood combs in heat, reduces bearding, and buffers the brood nest from draft so the queen will use the lower portion of the bottom combs; none of this has been tested in controlled trials. The swarm-reduction claim is the least supported. It is plausible, not demonstrated, and a master-level candidate should say so rather than repeating it as fact.

Misconception: Radial extractors need the frames reversed halfway through; tangential ones do both faces at once. **Correction:** Exactly backwards. Radial extractors hold the frames like spokes with the top bar outward, so centrifugal force acts along the plane of the comb, and the upward tilt of the cells lets both faces empty without handling. Tangential extractors present one face to the basket wall and must be turned to empty the other.

Misconception: New comb is fine in a radial extractor as long as you do not overdo the speed. **Correction:** New pale comb has no cocoon reinforcement and blows out readily; old dark comb is structurally much stronger and tolerates radial extraction well. Extract new comb tangentially and slowly, or crush and strain, and warm the honey to about 90 to 95 degrees F so that less force is needed in the first place.

Misconception: Rendering wax from diseased comb sterilizes it. **Correction:** Rendering at ordinary temperatures does not destroy *Paenibacillus larvae* spores, and it does not remove lipophilic miticide residues - it concentrates them, because the residue follows the wax. AFB comb and frames cannot be salvaged; burning or gamma irradiation is the standard, and woodenware may be scorchable depending on your inspection service's direction.

Misconception: A hive scale tells you when the colony has a mite problem. **Correction:** A scale measures net colony mass and nothing else. Mite infestation has no distinguishable weight signature. What the curve does show is flow onset and end, dearth, overnight consumption, swarm departures as a sudden mid-morning drop, and robbing as a rapid asymmetric gain. It is an outstanding instrument for building a local bloom calendar; it is not a diagnostic for anything inside the brood nest.

Misconception: Deep shade is the kindest place for hives in a hot climate. **Correction:** Some afternoon shade is valuable, but full-day deep shade keeps the soil surface damp, and soil moisture is the controlling variable for small hive beetle pupation - roughly 91.5 percent emergence from wet soil versus essentially none from dry. A deeply shaded yard is efficiently recycling its own beetle population. Aim for morning sun with light afternoon shade and sun reaching the ground for part of the day.

Misconception: Fire ants can be kept off hives with a good perimeter treatment around the yard. **Correction:** The workable method is to put hives on stands so that ants must follow a defined path, then treat that path - legs in oil cups or coated with grease or sticky barrier - and to keep vegetation cleared so nothing bridges the barrier. Without a stand the hive sits in the ants' foraging substrate and no barrier exists to defend. Baits, where used, go on mounds at a distance from the hives, on label, so hive products are not contaminated.

Misconception: A water source can wait until the bees look like they need one. **Correction:** By then they will have found one, and it will be a neighbor's pool, a stock tank or a dog bowl. Bees show strong fidelity to an established water source and are very difficult to move off it. Put water in the apiary before or with the colonies, keep floats in it, keep it filled through the dry months, and accept that slightly "dirty" water competes better than clean.

6.16 Self-Check Questions

- A beekeeper reports that in one particular hive the boxes are glued together with heavy burr comb at every junction, while in the hive beside it the boxes come apart cleanly but there is thick propolis at the junctions and dead workers crushed along the rims. Diagnose both hives in terms of bee space and give at least two plausible physical causes for each.
- Explain why nine-frame spacing improves honey supers but ruins a box of foundation, and state the operating rule that follows.
- A candidate says a screened bottom board "takes care of a lot of the mites." Correct the statement, state what the device actually does well, and name the specific management failure that the misconception causes.
- Give the functional gap of a queen excluder in millimeters and explain two distinct reasons why brood can appear above a correctly specified excluder.

- A beekeeper in the coastal plain seals every hive tight in November, tapes the inner cover down and closes all upper vents, reasoning that cold is what kills colonies. Explain what will happen and why, and describe three interventions that address the actual problem.
- Estimate the honey cost of drawing out one ten-frame deep box of comb, showing the reasoning, and then explain why that direct cost understates the true cost during a spring flow.
- You run a 40-colony sideline operation on two-deep brood chambers with medium supers and want to convert to all-mediums. Describe how you would do it and over what period, and explain how the conversion can be made to pay for part of the comb rotation you should be doing anyway.
- Distinguish the geometry-based and widely reported functions of a slatted rack from the swarm-reduction claim, which is the least supported and not demonstrated, and explain why the distinction matters at master level.
- Give at least six siting considerations for a new apiary in the southeastern coastal plain, and for each give the mechanism - not just the recommendation.
- Explain, with the experimental evidence, why full-day deep shade is a poor choice for a yard in the region even though afternoon shade is valuable.
- A colony on a hive scale shows a loss of about four pounds at 11:20 on a warm April morning, then resumes a normal daily gain. A second colony in the same yard shows a gain of six pounds between 14:00 and 16:00 on a day in late July with no flow. Interpret both records.
- A tropical system is forecast to reach your yards in 48 hours. List, in priority order, what you do, and say what you expect to be dealing with in the week after the storm.
- A beekeeper has a deadout with classic American foulbrood scale in the brood comb. State precisely what can and cannot be salvaged from that hive and why, and explain why a course of oxytetracycline would not have solved the problem.
- Compare wired wax foundation, plastic foundation and foundationless frames on three axes: acceptance by the bees, structural performance in extraction, and residue. State which you would choose for a spring package being installed during the main flow, and why.

6.17 Self-Check Answers

- The first hive has an oversized gap at the junctions - greater than about 9 mm - so the bees are filling it with comb. Likely causes: a bottom-bee-space box set on top of a top-bee-space box (the two spaces stack to roughly 3/4 inch), warped box rims, a frame rest rabbeted too deep, frames with undersized top bars, or a box run with fewer frames than it should carry. The second hive has an undersized gap - below about 6 mm - so the bees are propolizing and getting crushed. Likely causes: the reverse mixing order, so two flush surfaces meet with no space at all; swollen or repeatedly painted rims; years of accumulated propolis narrowing the junction; or frames lifted by comb built on the bottom bars.
- At nine-frame spacing each frame gets about 1 5/8 inches instead of 1 3/8, and bees hold the bee space between comb faces while putting the surplus into cell depth, so comb comes out around 1 1/4 inches thick instead of about an inch. The capping surface stands proud of the

wood, so an uncapping knife takes it in a clean pass, and there are fewer frames to handle per pound. Foundation is different because bees need an accurate reference plane to build straight comb, and drawn comb supplies that where a lone sheet of foundation does not. Foundation spaced wide produces wavy, cross-built comb bridged from frame to frame. The rule: draw comb at the full frame complement and reduce spacing only afterward, with spacers or a follower to keep the frames evenly positioned.

- A screened bottom board produces at most a small reduction in mite population - individual field trials found no meaningful effect, and a pooled meta-analysis found a statistically significant but modest one. It is not a control measure. What it does well is monitoring: mites that fall naturally or are groomed off drop through the mesh onto a board you can count, giving a cheap trend line between alcohol washes. It also provides real ventilation in a southeastern summer, and some beetle traps use the space beneath it. The management failure is that a beekeeper who believes the screen is treating the mites skips a fall treatment, and the colony collapses in October under a mite-vectored virus load.

- The functional gap is approximately 4.1 to 4.4 millimeters, which passes a worker's thorax and blocks the wider thorax of a laying queen. Brood above a correctly specified excluder can arise from hardware or from biology. Hardware: the excluder is distorted, bent, corroded or poorly manufactured, so one slot somewhere is wider than specification - the tolerance is tenths of a millimeter, so it does not take much. Biology: a small queen from poor rearing conditions can pass a sound excluder, and more commonly the colony superseded below, a virgin - narrower in the abdomen and far more agile - walked up through the excluder, mated, and is now laying above it.

- Metabolic water vapor from a cluster consuming 20 to 40 pounds of stores rises and condenses on the coldest surface, which in a sealed hive is the underside of the cover, and drips back onto the bees. Cold does not kill a dry colony; cold water does - the cluster is soaked, cannot hold temperature, and fungal problems follow. In a mild wet southeastern winter the colony is often still rearing brood, so vapor production stays high, and the problem is if anything worse rather than better. Three interventions: a small upper vent or notched inner cover so warm moist air leaves at the top; a slight forward tilt so any condensate drains out the entrance; and insulation above the cluster, which raises that surface above the dew point so condensation forms low on the outer walls instead of over the bees.

- A deep frame of drawn comb carries on the order of 100 grams of wax, so a ten-frame deep is about a kilogram, roughly 2.2 pounds. At the classical conversion figure of 6 to 8 pounds of honey per pound of wax, the direct cost is roughly 13 to 18 pounds of honey. That understates the true cost because wax-secreting bees are bees not foraging, and comb building only happens during a flow. In the southeastern US the spring flow may run only three to five weeks; a colony given foundation spends the early part of that window building rather than storing, and much of what it does gather goes into the comb. A colony given drawn comb starts filling on day one. The difference over a short flow is most of the crop.

- Convert over two to three seasons by consistently buying and supering only mediums, and by cycling deeps upward and out of the operation as they empty. Each season, move the deeps to the top of the stack in spring where the queen will not lay in them, let them be backfilled with honey during the flow, pull and extract them at harvest, and then retire the box rather than returning it. Replace below with medium boxes drawn during the flow. This pays for part of the

comb rotation because the deeps you retire first should be the oldest, darkest brood comb in the operation - the comb you were supposed to be culling anyway at roughly 20 percent a year. Trying to convert in one season fails: you would have to ask every colony to draw a full nest of foundation during the only flow that would otherwise produce a crop.

- Follows from geometry: the slatted rack creates clustering space below the combs, so bees hang there in hot weather instead of bearding on the hive front. Widely reported by beekeepers but untested in controlled trials: it buffers the brood nest from the draft of air entering the entrance, with the visible result that the queen lays to the bottom bar of the lowest frames instead of leaving the bottom inches empty. Least supported: the claim that a rack reduces swarming by relieving congestion beneath the brood nest. It is plausible, since brood nest congestion is a genuine swarm trigger, but it rests on beekeeper observation, and none of the three claims has been tested in controlled trials. The distinction matters because distinguishing a supported claim from a widely repeated one is itself part of master-level competence, and because a candidate who teaches unsupported claims as fact propagates them.

- Morning sun with light afternoon shade: early flight while heat-stress load and bearding are reduced. Well-drained ground above flood level: standing water chills colonies, fouls comb and kills brood, and colonies that survive a storm's wind are commonly lost afterward to water. Good air drainage rather than a hollow: cold air is denser and pools at night, so a frost pocket means colder nights, later build-up and more moisture. Vehicle access adequate in wet conditions: supers weigh 50 to 60 pounds and winter feeding still has to happen in February. A water source established before the bees find one: colonies need water for brood food and cooling and show strong fidelity to an established source, so if you do not supply one they will learn the neighbor's pool. Winter wind protection and a southeast-facing entrance: wind on the entrance chills the hive and costs stores. Stands 16 to 24 inches high (18 or more where skunks are active): above damp ground and minor flooding, and they create the defined path that fire-ant barriers depend on. Separation from neighbors with a six-foot flyway barrier: forces bees above head height at the boundary, and tethered or penned animals that cannot escape a disturbed colony are the specific hazard behind most nuisance actions.

- Small hive beetle larvae leave the hive to pupate in soil. Ellis and colleagues (2004) showed that soil moisture is the dominant variable: about 91.5 percent of larvae emerged as adults from wet soil treatments and essentially none emerged from dry soil, while soil type itself made comparatively little difference. Meikle and Diaz (2012) added that depth matters - high success at 4 to 8 cm of soil, almost none at 1 cm, none at 0 to 0.5 cm. Deep full-day shade keeps the soil surface damp, so a shaded yard efficiently recycles its own beetle population. A site where sun reaches the ground for part of the day and the soil dries between rains breaks a large fraction of the beetle life cycle at no cost, which is why the regional formula is partial shade rather than dense woods.

- The April record is a swarm. A loss of several pounds within minutes, in mid-to-late morning on a warm day in the swarm season, with normal gain resuming afterward, and no visit logged, is almost certainly a swarm - the departing bees are the lost mass, and the remaining colony continues to forage. Absconding or a manipulation such as pulling a super can give a similar step, so check the management log. The July record is robbing, and your colony is the robber, not the victim. A six-pound gain in two hours is far faster than any flow could deliver, and it is occurring during the summer dearth when there is nothing to gather. Expect a matching rapid

loss on some other colony - possibly in the same yard, possibly a weak neighbor's - and expect to find the source and either close it up or remove it.

- Priority order: move colonies off flood-prone low ground if you have a destination and the track is still passable, because flooding is what kills the colonies that survive the wind; strap each hive from bottom board through cover and strap or anchor the stand to the ground, since separated boxes mean destroyed combs; reduce stack height by pulling or consolidating supers, because a tall stack is a lever arm; weight lids where strapping is impossible and remove loose equipment that would become projectiles; clear dead limbs over the yard if there is time. Afterward, expect impassable access for days and possible chainsaw work; expect to right and reassemble colonies quickly before they are robbed out; expect to feed, because the system will have stripped forage over a wide area and ended the flow early; expect severe robbing pressure, so feed internally with entrance reducers in; expect a second wave of losses to standing water and get hives up on blocks; and document losses contemporaneously for disaster assistance.

- Nothing containing comb can be salvaged. *Paenibacillus larvae* spores remain viable for decades - thirty-five years and beyond - and are not killed by rendering the wax, by ordinary cleaning, or by antibiotics. The frames, comb, honey and bees are destroyed, normally by burning in a pit with the ashes buried, as most jurisdictions require or direct. Hive bodies, bottom boards, covers and metal parts can in many jurisdictions be salvaged by scraping and then scorching the interior surfaces with a torch until uniformly charred (not merely browned), and whole hives including comb can be salvaged by commercial gamma irradiation where a facility exists. Oxytetracycline would not have solved it because antibiotics suppress the vegetative stage only; they leave the spore reservoir in the comb intact, so the disease returns when treatment stops. That is also why these products have required veterinary oversight since 1 January 2017 and why prophylactic feeding is no longer lawful.

- Acceptance: wax is drawn most readily in any conditions; foundationless is drawn readily but requires level frames and disciplined early inspection or the comb wanders; plastic is drawn reluctantly except by a strong colony in a strong flow, and benefits from extra wax coating. Structure: plastic is much the strongest and survives radial extraction even when new; wired wax is adequate if the wire is embedded; foundationless comb is weakest and should be extracted tangentially and slowly or crushed and strained. Residue: commercial wax foundation carries industry-wide contamination - 98 percent of comb and foundation samples in the Mullin survey were contaminated, with fluvalinate to 204 ppm - while plastic carries residue only in its coating and foundationless carries none at all. For a spring package installed during the main flow I would use wax foundation or foundationless: the package has no drawn comb and must build a nest quickly, acceptance is the binding constraint, and a package hived on a flow is the one situation where foundationless works easily. Plastic would be the choice for honey supers that will go through a radial extractor and be scraped and reused.

6.18 Further Reading

- Langstroth, L. L. *Langstroth on the Hive and the Honey-Bee*. 1853. The original statement of bee space and the movable-frame principle; still worth reading for the reasoning, not just the history.

- Graham, J. M. (ed.). *The Hive and the Honey Bee*. Dadant & Sons, 2015 edition. The standard reference for equipment dimensions, hive components, extraction equipment and apiary management.
- Sammataro, D., and A. Avitabile. *The Beekeeper's Handbook*, 5th edition. Cornell University Press, 2021. The best single source for equipment illustration and for the practical mechanics of frames, foundation and extraction.
- Root, A. I. *The ABC and XYZ of Bee Culture*, 41st edition. A. I. Root Company. Encyclopedic entries on excluders, slatted racks, bottom boards, foundation and comb management.
- Morse, R. A., and K. Flottum (eds.). *Honey Bee Pests, Predators, and Diseases*, 3rd edition. A. I. Root, 1997. Still the standard reference on fire ants, skunks, bears and other apiary predators.
- Delaplane, K. S. *First Lessons in Beekeeping*. Dadant & Sons. Written by the University of Georgia's apiculture program and regionally grounded in southeastern practice.
- Ellis, J. D., K. S. Delaplane, and W. M. Hood. Efficacy of a bottom screen device, Apistan, and Apilife VAR, in controlling *Varroa destructor*. *American Bee Journal* 141 (2001): 813-816. The southeastern field trial behind the standard statement that screened floors are not a mite control.
- Liu, F., Xu, X., Zhang, Y., Zhao, H., and Huang, Z. Y. "A Meta-Analysis Shows That Screen Bottom Boards Can Significantly Reduce *Varroa destructor* Population." *Insects* 11, no. 9 (2020): 624. The pooled analysis that qualifies the single-trial results; read it alongside Ellis et al.
- Ellis, J. D., H. R. Hepburn, K. Luckman, and P. J. Elzen. "Effects of Soil Type, Moisture, and Density on Pupation Success of *Aethina tumida*." *Environmental Entomology* 33, no. 4 (2004): 794-798. The experimental basis for the shade-moisture-beetle connection.
- Meikle, W. G., and R. Diaz. "Factors affecting pupation success of the small hive beetle, *Aethina tumida*." *Journal of Insect Science* 12 (2012): 118. Soil depth requirements for pupation.
- Meikle, W. G., and N. Holst. "Application of continuous monitoring of honeybee colonies." *Apidologie* 46 (2015): 10-22. What a hive scale record can and cannot resolve.
- Mullin, C. A., M. Frazier, J. L. Frazier, et al. "High Levels of Miticides and Agrochemicals in North American Apiaries: Implications for Honey Bee Health." *PLOS ONE* 5, no. 3 (2010): e9754. The residue survey that justifies comb rotation and caution about commercial foundation.
- Mitchell, D. "Ratios of colony mass to thermal conductance of tree and man-made nest enclosures of *Apis mellifera*: implications for survival, clustering, humidity regulation and *Varroa destructor*." *International Journal of Biometeorology* 60 (2016): 629-638. The thermal comparison behind hive insulation; Mitchell also argues that retained humidity is beneficial.
- University of Georgia Cooperative Extension, honey bee program publications - including guidance on apiary siting, small hive beetle management and disaster preparedness for beekeepers.

- Clemson University Cooperative Extension and the Clemson Apiculture and Pollinator Program - regional publications on apiary establishment, fire ant management around hives, and hurricane preparedness.
- University of Florida IFAS Extension, Honey Bee Research and Extension Laboratory - EDIS publications on small hive beetle biology and management, hive equipment, and preparing colonies for tropical storms.
- NC State Extension Apiculture Program - publications on apiary site selection, equipment and seasonal management for the piedmont and coastal plain.
- Auburn University and the Alabama Cooperative Extension System - beekeeping publications covering equipment, siting and regional pest pressure.
- LSU AgCenter - Gulf coastal beekeeping publications, including hurricane preparation and recovery guidance for apiaries.
- Honey Bee Health Coalition. *Tools for Varroa Management*, 9th edition, 2026. For the monitoring context in which a screened bottom board's mite-fall counts are actually used.
- USDA Farm Service Agency. Emergency Assistance for Livestock, Honeybees and Farm-raised Fish (ELAP) program materials, for the documentation required after a storm or other disaster loss.

Chapter 7. The Southeastern Beekeeping Year – Seasonal Management

Covers exam questions Q115-Q139.

7.1 Orientation

Almost every widely read beekeeping book in English was written for a climate the southeastern US does not have. The standard year those books describe has a long, cold, broodless winter, a spring that begins in April, a build-up that runs into a June flow, a harvest in late summer, and a short autumn window in which the beekeeper feeds, treats and wraps. A candidate who has internalized that year and transplants it here will be late to every decision that matters. He will start swarm inspections after his swarms have left, he will treat for mites after the winter bees are already damaged, he will feed thin syrup into a hive that cannot ripen it, and he will insulate a colony against a cold that is not the problem while ignoring the moisture that is.

The southeastern year has a different shape, and the exam tests whether you know the shape and, more importantly, what drives it. Three ideas organize this chapter.

The first is that **the season opens early and closes late.** Red maple (*Acer rubrum*) sheds pollen in the coastal plain in January and in the piedmont in February, and willow, elm, alder, henbit and dead nettle follow. That pollen is the trigger for serious brood rearing, and once it arrives colonies expand while northern colonies are still clustered and broodless. Everything downstream moves with it: swarm season opens in late winter, the main flow runs in April and May rather than June and July, splits are made in March, and the calendar's whole center of gravity shifts a month or more earlier. The corollary at the other end is that the productive season runs into October and colonies rear brood through most or all of the winter, which is the single fact that most changes mite management here.

The second is that **the midsummer dearth, not the winter, is the hazardous season.** In the upper Midwest the colony's hard test is January. Here the hard test is July and August, when forage collapses at the hottest time of year while the mite population is climbing toward its annual maximum, small hive beetle is at its seasonal peak, and the beekeeper has just removed the colony's honey. Starvation, robbing, beetle slime-out, absconding, queen failure and mite-plus-virus damage to the developing winter bees all cluster in this one period. A management year built for this region is essentially a plan for getting colonies through the dearth intact.

The third is that **every one of these hazards is anticipated rather than reacted to.** By the time you can see the problem - the robbing frenzy, the slimed comb, the dwindling March colony - the decision point was weeks or months earlier. The examiner at this level is probing whether you can name the decision point and say what drives it. That is why this chapter is organized as a calendar with mechanisms attached rather than as a checklist.

7.2 The Shape of the Year

The region is not uniform. Elevation and distance from the coast shift everything by weeks, and the three broad physiographic divisions - the coastal plain and Gulf coastal areas, the piedmont, and the southern Appalachian mountains - can differ by a month at the same latitude. Treat the table below as a frame whose dates you will recalibrate for your own site by the method in the last section of this chapter.

Period	Coastal plain / Gulf	Piedmont	Southern Appalachians	What the colony is doing
First pollen, brood rearing restarts	January	Late January to February	February to March	Brood nest expands from a few hundred cells to several frames
Build-up, swarm season opens	Mid-to-late February	Early-to-mid March	Late March to April	Population doubling roughly every brood cycle; drones flying
Main flow	April into May	Mid-April to late May	May into June	Maximum population, maximum storage
Specialty flows	Tupelo early to mid spring; gallberry late April to May; palmetto late May	Privet, clover, sumac	Sourwood late June into July	Narrow, high-value windows
Dearth	Late June through August	Late June through August	July through August	Contraction; stores consumed; mites peak
Autumn flow	September into October	Late September into October	September	Goldenrod and aster; winter bees reared
Winter	November to January, rarely broodless	November to February, brief or no broodless window	December to February, sometimes broodless	Small cluster, intermittent brood, breaks cluster on warm days

The surplus crop is overwhelmingly the spring flow. Tulip poplar (*Liriodendron tulipifera*) is the anchor across the piedmont and lower mountains, running roughly mid-April to mid-May, joined by blackberry and dewberry (*Rubus* spp.), black locust (*Robinia pseudoacacia*), the clovers, hollies including gallberry (*Ilex glabra*) in the coastal plain, and privet (*Ligustrum* spp.), which produces heavily and tastes of it. Two narrow varietals are the region's signature crops: tupelo, principally Ogeechee tupelo (*Nyssa ogeche*) in a handful of river swamp systems, and sourwood (*Oxydendrum arboreum*) at the higher elevations in late June and July. Both are short, both are weather-dependent, and both reward a particular discipline discussed below.

The autumn flow on goldenrod (*Solidago* spp.) and aster (*Symphyotrichum* spp.) is real but is not the region's crop. It is the region's winter feed and, more importantly, its winter protein.

7.3 Late Winter: The Trigger

7.3.1 What actually restarts brood rearing

A colony never fully stops rearing brood in most of this region, but it does contract to a small patch through the coldest weeks. What expands that patch is pollen. The mechanism is nutritional and mechanical at once: nurse bees must consume pollen to develop their hypopharyngeal glands and secrete the jelly that larvae are fed, and stored beebread is a depleting asset. A colony with a full complement of nurse bees and no incoming pollen will rear some brood on its reserves and then throttle back. Give it fresh pollen and the constraint lifts.

This is why red maple matters so much here. It blooms in the coldest part of the year - January in the warmer coastal plain, February across most of the piedmont - and it is a heavy, reliable pollen source at a moment when nothing else is producing. Willow (*Salix* spp.), elm (*Ulmus* spp.), alder (*Alnus* spp.), henbit and dead nettle (*Lamium* spp.), the early brassicas and the early fruit bloom follow within a few weeks. Nectar at this point is thin and unreliable; it is the pollen that does the work.

The consequence is that a well-provisioned southeastern colony can be carrying brood on six to eight frames in late February, at a point in the calendar when a colony in the upper Midwest is still a fist-sized cluster on stores with a few hundred cells of brood. Everything the region's beekeepers do in the following ten weeks follows from that head start.

7.3.2 Why late winter is the hungriest moment

Here is the counterintuitive point the exam likes. Colonies in this region are more likely to starve in February and March than in December. Two things converge. First, brood rearing is metabolically expensive: the brood nest must be held near 95 degrees F regardless of outside temperature, and the bees fuel that with honey. A colony rearing brood on six frames burns stores several times faster than the same colony clustered and broodless. Second, the stores available have been drawn down all winter and the new flow has not yet arrived in volume. The colony is spending at its maximum rate against a nearly empty account, and a two-week cold, wet spell that grounds the foragers finishes it.

The regional aggravation is that mild winter weather makes this worse, not better. A colony that breaks cluster on a 65-degree day in January flies, forages unproductively, and rears brood. It consumes more stores than a continuously clustered colony of the same size. A beekeeper who left "plenty" in October by a northern rule of thumb and then did not check has an excellent chance of finding a dead colony with an inch of honey left in March.

7.3.3 Hefting and hive scales

The non-invasive way to know is to heft: lift the back of the hive an inch off the stand and feel the weight. That is all it is - an estimate of stored honey, and therefore of whether feeding is needed, without opening the hive and breaking the cluster's heat in cold weather. It is not a test of queenrightness, it does not dislodge beetles, and it has nothing to do with leveling the hive.

Hefting is crude on the first attempt and reliable after a couple of seasons, because it is a calibration exercise: you are learning what an adequately provisioned colony of your equipment type feels like. Heft the same hives repeatedly and note what you find when you eventually open them, and the sense becomes trustworthy. A hive scale under one representative colony in each yard gives the same information continuously and far more precisely, and it also gives you the daily gain-and-loss trace that tells you when a flow started and stopped. Either is enormously better than assuming that a colony heavy in October is still heavy in February.

7.3.4 Reversing brood boxes: a conditional manipulation

Over winter the cluster moves upward, consuming the honey above it. By late winter the colony has frequently ended up in the top box with the bottom box empty, and the brood nest is pressed against the inner cover with nowhere to expand. Reversing - putting the empty lower box on top - puts the expansion room where the colony is growing.

The manipulation is correct **when the cluster and brood have in fact moved up and the lower box is empty.** It is wrong on a fixed date, and it is wrong when brood spans both boxes. Splitting a brood nest across a box boundary in February and then getting a hard freeze can strand part of the brood away from the cluster, where it chills and dies, and a colony that loses half its brood in late winter has lost its build-up.

This caution matters more here than in the north precisely because our late winter is a sequence of warm spells and cold snaps rather than a steady thaw. A 70-degree week in February invites the manipulation; the 24-degree night ten days later punishes it. If you are unsure, add drawn comb above rather than reversing. Space added on top is never wrong; boxes reshuffled around an actively expanding brood nest can be.

7.4 Spring Build-up and the Opening of Swarm Season

7.4.1 Why inspections start in late winter

Swarm control is almost entirely a timing problem, and the timing is set by queen development. From the egg laid in a charged cup to a sealed queen cell is eight days, and the prime swarm leaves at or just after that capping. A seven-day inspection interval is therefore the longest cadence that guarantees you cannot miss the window: a cup charged the day after you close the hive is still open, and still destroyable within a manipulation, when you return.

The regional point is when that cadence must begin. Colonies here can reach swarming condition - large population, backfilled brood nest, surplus of young bees, mature drones flying - in **mid-to-late February in the coastal plain and Gulf coastal areas, early-to-mid March in the piedmont, and late March into April in the southern Appalachians.** A calendar written for a northern state will tell the reader to start weekly inspections in late April. In the coastal plain that is two months late, and the answer to “when should I start looking for cells” is not “after I see a swarm leave” and certainly not “after the main flow has begun.”

Two operational consequences follow, and both are examinable. First, the manipulations that relieve the swarming impulse - splitting, the Demaree, opening the brood nest with drawn comb, checkerboarding, the first supers - must be performed *before* the colony has made its decision, which means the equipment must exist in late winter. Supers must be assembled, foundation wired, drawn comb pulled from storage and checked for wax moth damage, nucleus boxes built, and queens ordered, all in December and January. A beekeeper who begins building equipment in March in this region is building equipment to house swarms that have already gone. Second, swarm traps and bait hives go out before the first inspections, not after.

The second, less obvious consequence is that the dearth also does not produce reproductive swarming. Swarming is a response to prosperity - forage coming in, young bees in surplus, drones available. A colony deprived of forage in July does not divide to improve its odds; if it leaves at all it absconds, which is a different event with a different cause and a different remedy.

7.4.2 Splitting: four objectives at once

Spring splitting is the most common single management operation in the region, and the reason it is so common is that it achieves four things simultaneously.

It controls swarming, by removing the population and brood that generate the impulse. It makes increase. It replaces the losses the operation expects - a meaningful consideration when national annual losses ran 55.1 percent in 2023-24 and 55.6 percent in 2024-25, and even the improved, preliminary 2025-26 figure of 39.9 percent is roughly double what beekeepers themselves call acceptable at 15 to 20 percent. And it creates a brood break in the queenless half - the half raising or receiving a new queen - which is genuinely useful in mite management because it strands mites on adult bees where a single-application treatment can reach them. The half that keeps the laying queen gets a break only if that queen is also caged or removed.

The season here is long enough that both halves can build to wintering strength, which is what makes routine spring splitting practical. In a short-season climate the same split leaves you with two colonies too small to winter.

The trade-off is the crop. A split made immediately before or during the main flow costs surplus from both halves, because a colony’s surplus is what remains after it pays its own maintenance, and maintenance does not halve when the population does. One very large colony on the tulip poplar flow will out-produce two medium ones by a wide margin. The honey-focused response is to use a manipulation that relieves congestion without dividing the foraging force - the Demaree is the standard - or to take increase after the flow rather than before it.

Splits made *during* the midsummer dearth are a different proposition and largely a bad one. A small colony in July has no incoming forage, cannot defend itself against robbers, cannot patrol its own comb against small hive beetle, and must mate a queen in heat. Such splits need feeding, beetle protection and close attention, and they fail at a much higher rate. Timing matters here as much as technique.

7.4.3 Honey-bound and pollen-bound brood nests

During a heavy flow the colony may fill its own brood nest with nectar. The mechanism is simple: returning foragers deposit their loads in the first available cells, and if storage space above is insufficient, is not yet drawn, or is inaccessible, the available cells are the ones in the brood nest as brood emerges. The brood nest is progressively backfilled, the queen has nowhere to lay, and her laying rate falls.

This is the **honey-bound** condition, and it is a swarming accelerant twice over: it restricts the queen physically, which reduces both her egg-laying and the area over which she deposits footprint pheromone, and it produces exactly the congested, nectar-packed nest that the colony reads as a signal to reproduce.

The response has two parts and both are needed. Give storage space immediately - supers, and drawn comb rather than foundation wherever you have it, because a colony under pressure fills drawn comb in days and draws foundation in weeks. And restore laying space directly, by inserting empty drawn frames into the brood nest or by lifting nectar-filled brood frames up into a super and replacing them below with empty comb. While you are in there, verify that a queen excluder, if used, is flat, unbroken and not gummed with propolis or burr comb, since a damaged or obstructed excluder can deter the bees from using the space above it, and confirm the colony has the ventilation to evaporate what it is bringing in.

Pollen-bound presents almost identically - a ring of beebread expanded until it crowds the brood - and takes the same remedy of providing laying space, usually by moving the worst combs to the outside or out of the nest entirely. Both conditions must be distinguished from a failing queen, because the visible sign is the same: not much brood. The distinction is what occupies the cells. A honey-bound or pollen-bound nest has full combs of the wrong thing and a healthy queen; a failing queen leaves empty, available cells unfilled, or fills them with a spotty or drone-heavy pattern.

7.4.4 Equalizing colonies, and its principal risk

Moving frames of brood from strong colonies to weak ones before a flow or a pollination contract is a legitimate tool, and it is widely overused. Its principal risk is that it is an efficient mechanism for distributing disease, mites and pests through an apiary. A frame of brood carries whatever the donor carries: *Paenibacillus larvae* spores, European foulbrood, chalkbrood, viruses, *Vairimorpha (Nosema) ceranae*, mites in the capped cells, and beetle eggs. Blind equalization through a yard is one of the standard ways foulbrood is spread from one colony to all of them.

The second risk is diagnostic. A weak colony is weak for a reason. If the reason is a failing queen, a poorly mated queen, a disease or a mite load, adding brood does not fix it - it props the colony up temporarily, masks the cause, and in the case of a failing queen simply donates bees to a colony that will fail anyway. The disciplined sequence is: establish why the colony is weak; address that cause; and only then, if the colony needs population and is otherwise sound, take brood from a donor whose health you have verified, without weakening the donor below its own needs.

Equalization does not cause swarming reliably, it is not prohibited by law, and brood combs transfer between colonies perfectly well - worker bees do not reject brood from another queen.

7.5 The Main Flow and Supering Discipline

The main flow is the shortest-attention part of the year and the part where the beekeeper's errors are cheapest, which is why the exam tends to test it through the two operations that require real discipline: supering ahead of need, and producing a segregated varietal crop.

Super ahead of need, not at need. A colony that runs out of storage space mid-flow backfills its brood nest within days, and the swarming impulse follows. The rule of thumb is to add the next super when the current one is about two-thirds occupied, and to be more generous with foundation than with drawn comb because foundation will not be drawn at all unless the colony is under flow pressure with wax-secreting-age bees available.

The critical constraint that links this section to mite management is that **many miticides require honey supers to be off - amitraz, the thymol products, the pyrethroid and coumaphos strips, and the dsRNA product Norroa. Formic acid, the oxalic acid products (including the VarroxSan strip), HopGuard 3, and the newer l-glutamic acid (MBG2X5G) and sucrose octanoate (OrganiShield) products are labeled for use with supers on,** within their temperature limits and, for VarroxSan, provided at least one box separates the treated brood chamber from any honey to be extracted. The supers-off restriction is not incidental; it structures the treatment calendar. In practice it means the region has two workable treatment windows: late winter and early spring before the first supers go on, and the period from the end of the main flow to the beginning of autumn build-up. Anything you intend to do with a synthetic acaricide or a thymol product must fit into one of those two windows, which is one more reason the late-summer decision described below is so consequential.

7.5.1 Producing a varietal crop

Sourwood and tupelo are the region's premium varietals, and both command prices that justify a specific discipline. The steps are these, and they are worth memorizing as a sequence because the exam can ask for the critical one.

Build colonies to full strength ahead of the target bloom, and manage swarming so the foraging force is intact when it starts - a colony that swarms in early June will not make a sourwood crop. Complete any needed mite treatment before the clean supers go on, since many products require supers off, and finishing treatment first keeps the varietal crop clear of any question. **Remove and extract all previously stored surplus before the target bloom begins, so that each colony is left with clean, empty drawn supers.** Place those clean supers immediately before or at the very start of the bloom. Remove and extract them promptly when the bloom ends, before the bees begin adding honey from whatever follows. Keep the crop segregated through extraction, settling, storage and bottling, which in a small operation usually means extracting it on a separate day and labeling every bucket.

The single most important step is clearing the supers before the target bloom, because anything already in those combs is extracted along with the varietal and dilutes it. A sourwood crop contaminated with tulip poplar is tulip poplar honey with a story attached.

The same discipline pays a second time in the opposite direction. Privet honey is strong and not to everyone's taste, and goldenrod is strongly flavored and unmistakably odorous while curing. Pulling supers cleanly before those sources come in is how you keep a light table crop light.

7.6 The Midsummer Dearth

This is the section to know cold. In most of the region the flow ends somewhere between late May and late June, and from then until the goldenrod comes in around mid-September there is very little nectar and often very little pollen, at the hottest time of year. The colony is at or near its maximum population, its stores have just been removed by the beekeeper, and it has nothing coming in. Everything goes wrong at once, and it goes wrong in ways that are causally linked.

7.6.1 Starvation

A large colony consumes several pounds of honey a week doing nothing in particular, more in heat because evaporative cooling costs water-carrying flights and fanning. Remove the supers and leave a colony with a light brood chamber, and you have three to four weeks before it is in trouble. Colonies that "starved in the middle of summer" are not a curiosity here; they are the standard failure of the beekeeper who harvested everything and went on vacation. The specific warning sign is a colony that was heavy at harvest and is light at the next visit, which is why hefting is a July practice as much as a February one.

7.6.2 Robbing

Robbing is the dearth's signature behavior and it escalates on a positive feedback loop. Foragers with nothing to collect search more widely and probe other colonies' entrances. A colony that is weak, queenless, small-population or recently disturbed cannot defend its full entrance. Once robbers breach it, they recruit, and a strong neighboring colony can strip a weak one of every ounce of honey in a matter of hours, killing bees and often the queen in the process. Worse, robbing is a transmission event: mites, viruses and foulbrood spores move with the stolen honey, which is how one dead-out with a mite problem seeds an entire apiary.

Prevention is structural and it is preventive rather than reactive. Reduce entrances to a size the colony's population can actually defend - a strong colony can hold a wide entrance, a five-frame nucleus cannot hold more than a couple of inches. Use robbing screens on weak colonies and on all nucs. Do not leave burr comb, cappings, wet supers or spilled syrup exposed in the yard. Work colonies quickly, with the hive open for the shortest time possible, and preferably in the evening. Feed inside the hive, never in the open, because open feeding in a dearth simply organizes the strong colonies to strip the weak ones. And do not leave a queenless or failing colony sitting in a dearth yard; combine it or requeen it.

7.6.3 Small hive beetle takeover of undefended comb

Aethina tumida is a southeastern beekeeper's permanent companion and its damage is a function of the ratio of adult bees to comb area. Adult bees patrol comb, harass beetles, and corral them into propolis prisons. Where comb is not patrolled, beetles lay, the eggs hatch in about two to three days, and larvae feed for roughly ten to fourteen days before leaving the hive to pupate in the soil for three to five

weeks. A few dozen larvae is a nuisance; a few thousand is slime-out, in which the honey ferments, the combs are ruined, and the colony absconds from its own hive.

The dearth is when this goes wrong because every factor moves the wrong way at once. Beetle populations are at their seasonal peak in the warm months. Colonies are contracting as brood rearing slows under nutritional stress, so the adult population covering the comb falls. And the beekeeper has often just added boxes or left wet supers on, increasing the comb area to be patrolled. The management response is to **match comb to bees**: consolidate colonies down to the space they can cover, remove and store wet supers promptly rather than leaving them on to be cleaned, keep beetle traps serviced, and never leave a weak colony in a large box.

This is also the reason for the region's most distinctive feeding caution, discussed next.

7.6.4 Feeding in the dearth, and the protein-patty trap

There are two feeds and they do different jobs.

1:1 syrup, roughly equal parts sugar and water by weight, is close to nectar in concentration and functions as a *stimulative* feed. It signals a flow, and colonies respond by rearing brood, secreting wax and drawing comb. Use it in late winter and spring, when drawing foundation, and to start nucs.

2:1 syrup, roughly two parts sugar to one of water by weight, delivers far more carbohydrate per unit of water. The bees have to evaporate less to ripen it, so they can store it quickly and at low energy cost, which is exactly what you want when the objective is to build winter stores in autumn rather than to stimulate brood rearing.

Three cautions attach. First and absolutely: **never feed syrup while honey supers intended for sale are on the colony.** Stored syrup extracted and sold as honey is adulteration, and it is adulteration whether or not you intended it. Second, use plain white granulated sugar dissolved in warm - not boiling - water, and do not attempt to acid-invert it. Heating sugar solutions, particularly acidified ones, generates hydroxymethylfurfural (HMF), which is toxic to bees at elevated concentrations; raw sugar, brown sugar and molasses carry solids bees cannot digest. Third, syrup fed too late in the season leaves high-moisture stores the colony cannot ripen and cap, and uncapped stores ferment.

Protein is the harder problem. A colony under a long dearth runs down its beebread, and by late summer that shortfall reaches forward into the winter bee cohort. Protein supplement is the obvious answer, and in this region it carries a specific hazard: **protein patties are excellent small hive beetle larval substrate.** A large patty on a colony that lacks the population to patrol it becomes a beetle nursery, converting a nutritional intervention into an infestation. The practical rules follow directly: size the patty to a few days' consumption rather than laying in a month's supply, remove the paper backing so beetles have no sheltered gap to lay in, place it directly over the cluster where bees are dense, check it at every visit and remove any remnant that the bees are not covering, and **do not feed protein to a colony too weak to patrol it.** Every supplemental feeding decision in this region has to be evaluated against beetle pressure, which is not something a northern text will tell you.

Patties do not attract mites, do not suppress the queen's laying, and do not ferment into something bees refuse; the beetle problem is the real one.

7.6.5 Heat, water and absconding

Colonies cool themselves by evaporating water, which means that in July a colony's water requirement is comparable to its nectar requirement in spring. A hive in full afternoon sun in the coastal plain has a large fraction of its workforce committed to cooling instead of anything productive, comb can soften and collapse, and a colony pushed far enough will abscond outright. Afternoon shade and a reliable, close water source are not luxuries in this region; they are part of apiary design. Increased ventilation - screened bottom boards, a propped outer cover, an upper entrance - is the other half.

7.6.6 Queen failure and supersedure under nutritional stress

Queens are fed by nurse bees whose jelly production depends on protein intake. A colony in a protein-poor dearth reduces the queen's feeding, she lays less, her pheromone output falls, and colonies frequently respond by superseding. This is why queen problems cluster in late summer, and why the autumn queen check described below is not a formality.

7.6.7 Varroa reaching its annual peak

The mite population grows as a function of available brood, and it has been compounding all spring. By late summer it reaches its seasonal maximum - and it does so in a colony whose adult population is falling. Mites per 100 bees therefore rises much faster than mite numbers alone, because the denominator is shrinking while the numerator grows. This is the mechanism behind the late-summer decision that the next section treats on its own, because it is the single most consequential timing point in the year.

7.6.8 The post-flow transition: what to do in the weeks after the flow ends

The end of the main flow is a hinge. The colony switches from expansion to contraction, and the beekeeper's management has to switch with it. The actions, each with its reason:

Remove and extract supers promptly. This protects honey quality, and it removes acres of comb the contracting colony can no longer patrol against beetles. Left on, the honey will also simply be eaten during the dearth.

Reduce entrances. Robbing pressure rises the day the flow ends.

Assess weight and plan feeding. A colony that has just had its honey removed can starve in three to four weeks.

Do a mite count and treat if warranted. The supers are off, which is when most products are usable, and this is before the winter bee cohort is reared. This window is narrow and it does not reopen.

Deploy and service beetle traps, and consolidate boxes to the space the bees cover.

Check queen status and requeen failing colonies now, while there is enough season left for a new queen to establish, be accepted, and lay a population of winter bees.

Combine any colony too weak to defend itself - after verifying it is disease-free, since combining a foulbrood colony into a healthy one is how you lose both.

7.7 The Late-Summer Mite Decision

If you take one thing from this chapter, take this. **The bees reared in late summer and early autumn are the bees that will overwinter, and mite feeding and the viruses mites transmit damage them during pupation.** That is why late summer, not midwinter, not the main flow, and not early spring, is the year's most consequential monitoring point.

7.7.1 The mechanism

Winter bees, sometimes called diutinus bees, are physiologically distinct from summer bees. They are reared in autumn under conditions of good pollen availability and declining brood demand, and they accumulate large fat bodies and high circulating vitellogenin, which is what allows them to live four to six months instead of five or six weeks and to support brood rearing at the far end of the winter.

Varroa destructor feeds mainly on the fat body of adult bees - the work of Ramsey and colleagues in 2019 corrected the older textbook claim that mites feed only on hemolymph - and mainly on the hemolymph of pupae in the sealed cell (Han and colleagues, 2024), the nutrient supply from which the pupa builds its fat body. The fat body is precisely the organ that makes a winter bee a winter bee. A pupa parasitized by one or more mites emerges with reduced weight, a compromised fat body, lower vitellogenin, and frequently a viral infection, most importantly deformed wing virus. Dainat and colleagues found that winter bees from colonies that later collapsed lived significantly shorter lives, and that colony mite infestation and DWV infection were the factors associated with that shortening. The resulting bee looks entirely normal - it may have no deformed wings at all - and simply dies weeks before the colony can replace it.

This is the whole explanation for the most frustrating pattern in beekeeping: a colony that was strong, populous and productive in September is dead in January, with stores still in the hive and no obvious cause. The damage was done in August and September, to bees that were still pupae. By the time the colony visibly declines, the intervention window closed months ago.

Two corollaries are examinable.

First, **the decision must be driven by a measured mite count, not by the appearance of the colony.** A colony with a serious mite load in August looks excellent, because it still has its full summer population of healthy bees. Appearance is the least reliable input available at exactly the moment the decision is being made.

Second, **treatment must be completed before the winter bees are reared, not after damage becomes visible.** In practice that means the decision point falls from late July through early September depending on whether the apiary is in the coastal plain, piedmont or mountains, and the treatment must be finished - not started - by the time the colony is rearing the cohort that will winter. A treatment applied in November is too late to matter for that cohort, whatever it does to the mites.

This is also why the late-summer decision cannot be deferred. Current HBHC action levels are 1 percent during spring build-up and 2 percent at peak population and in late summer; the spring figure is lower because a small spring population has months of brood rearing ahead in which to compound. In late summer the stakes change: the mites are concentrating into a shrinking population and are feeding on

the irreplaceable cohort, so a count at or above 2 percent calls for treatment at once, with no later window in which to recover. The difference is not the mites - it is which bees they are damaging.

7.7.2 Verification is now the control that catches resistance

The single most important recent development changes what "treated" means. In the investigation of the 2024-25 loss event published by Lamas and colleagues in *PLOS Pathogens* in February 2026, **every one of 39 mites screened - 100 percent - carried the Y215H mutation in the Octbeta2R octopamine receptor gene**, the mutation conferring amitraz resistance, up from roughly 66 percent in earlier regional surveys. Every operation sampled had been relying on amitraz. In the same work deformed wing virus A was present in 78 percent of screened colonies and acute bee paralysis virus in 72 percent, ABPV at levels unusually high compared with prior surveys, and DWV-B was found in 100 percent of symptomatic bees.

The practical consequence is blunt: a beekeeper who applies amitraz and does not take a post-treatment count may be running an entirely uncontrolled mite population while believing the colony is protected. **Post-treatment verification is no longer good practice; it is the control that detects resistance.** Take a count before treating, treat, and take another count promptly at the end of the labeled treatment period, before reinvading mites can blur the result. A product that has not moved the number has failed, and you still have time to do something else - but only if you looked.

7.7.3 Working around a hot climate and a short window

Product selection in this region is constrained by heat in a way northern practice is not. Formic acid products are temperature-limited at the upper end, and applying them in a southeastern August risks brood loss and queen loss. Thymol-based products have both lower and upper temperature bounds and can drive bees out of the hive when it is very hot. Synthetic pyrethroid strips face long-standing resistance in many populations. Amitraz faces the resistance situation above. Oxalic acid does not penetrate cappings at all, which is the subject of the wintering section below.

There is no single right answer, and the craft genuinely disagrees. What is not negotiable is the sequence: monitor, choose a product whose label conditions your weather actually satisfies, apply it correctly and for the full label period, and verify.

7.8 Autumn: Goldenrod, Aster, and Building the Winter Population

7.8.1 Goldenrod and aster are nutrition, not crop

The autumn bloom on goldenrod and aster runs from roughly mid-September into October across most of the region. There is a legitimate market for goldenrod honey, and in good years a colony will put up a super of it. But its principal value in this region is that it supplies the late nectar and, more importantly, **the pollen that allows colonies to rear a healthy, well-provisioned winter population.** The protein in autumn pollen is what builds the fat bodies and vitellogenin stores that define a winter bee.

That reframing carries a management implication that the exam likes: **a poor autumn bloom is a management signal.** A dry September, or an apiary sited where goldenrod and aster are sparse, means the colony will attempt to rear winter bees on inadequate protein and will produce short-lived bees

whatever your mite counts say. That is the situation in which protein supplementation is genuinely indicated in autumn - subject, always, to the beetle caution, which means small patties on colonies strong enough to cover them.

Goldenrod nectar has a notably strong, sour odor while curing, which beekeepers in the region learn to recognize at the hive entrance and occasionally mistake for foulbrood. Goldenrod does not suppress small hive beetle, is not a premium light varietal, and is not the region's main crop.

7.8.2 Fall requeening, and why the long season makes it practical here

Requeening in autumn rather than spring has real advantages. A young queen entering winter lays a larger, more concentrated winter bee cohort; she is far less likely to fail or supersede during the following spring build-up, which is exactly when a supersedure is most expensive; and she produces more queen pheromone, so the colony is measurably less swarm-prone in its first spring. The drawback is acceptance: introduction is harder, not easier, during the late-summer dearth, when robbing pressure is high and colonies are less tolerant, so feed, reduce entrances and allow extra time. Good queens can also be harder to obtain late in the season.

The reason this is practical in the southeastern US and awkward in the north is simply season length. A queen introduced in early September here has six to eight weeks of brood rearing weather in which to be accepted, prove herself and lay a winter population, and mated queens are readily available from regional producers through the autumn because the queen-rearing season runs long. Introduce a queen in early September in the upper Midwest and you have a much narrower margin, with a colony that may be clustering within weeks of introduction and queen availability already thinning.

The regional caveats are the ones you would expect: requeen early enough that the new queen actually lays winter bees, do not requeen during the height of robbing without protecting the colony, and make the introduction after the mite treatment rather than in the middle of one.

7.8.3 The autumn checklist, and how the emphasis differs from northern practice

Complete these in early to mid autumn, each for a reason:

Confirm queenright status and pattern; requeen failures. A colony that enters winter queenless in this region does not rear replacement bees and will dwindle out.

Complete mite monitoring and treatment early enough to protect the winter bee cohort, and verify with a follow-up count. Discussed above; it is the highest-value item on the list.

Assess and build stores, feeding 2:1 syrup while temperatures still permit ripening and capping. The sequencing matters: feeding must be finished while the bees can still evaporate and seal it, or the stores you added become a fermentation problem.

Combine colonies too weak to winter, after confirming they are disease-free. Two weak colonies combined into one adequate colony is a better outcome than two dead ones, and the combined colony can defend and patrol comb.

Reduce entrances and fit mouse guards where rodents are a problem. Robbing pressure persists into autumn and mice move in as nights cool.

Remove queen excluders. The reason is specific and the exam asks it: the winter cluster moves predominantly upward as it consumes the stores directly above it, and if the queen cannot pass the excluder she is left behind below the ascending cluster and dies. It is not about brittleness, ventilation or regulation. If an excluder must stay for some other reason, ensure the queen is above it before winter or leave a passage around it.

Ensure the covers are sound, the hive is tilted slightly forward, and there is upper ventilation. Moisture, not cold, is the winter killer here.

Remove and properly store surplus supers, protected against wax moth and beetles, since undefended stored comb is destroyed within weeks in a warm climate.

The emphasis differs from northern practice in a way worth stating explicitly, because the exam builds distractors out of northern habits. **Insulation and wrapping are generally unnecessary in this region.** What matters instead is mite control, small hive beetle management, and moisture control. A southeastern colony wrapped in black tar paper and sealed tight is being protected against a cold that will not kill it while being held in the humidity that will.

7.9 Wintering a Colony That May Never Go Broodless

7.9.1 How much honey to leave: why no single figure is adequate

Beekeepers want a number, and the honest answer is that the number is a local measurement, not a published constant.

What sets the requirement is total metabolic demand over the interval between the end of dependable autumn forage and the return of dependable spring forage. That interval and that demand vary with the length and severity of winter at the specific site and elevation; with colony size and configuration, since a larger cluster in more boxes has more thermal surface and more bees to feed; with hive type, material and exposure to wind and sun; with stock, since some lines rear brood more persistently through winter than others; and with how early the first reliable pollen and nectar arrive, which in this region can differ by six weeks between the coastal plain and the mountains.

Southeastern colonies generally need less than colonies in the upper Midwest, where 80 to 90 pounds of honey is a common target. But - and this is the trap - they do not need proportionally less, because they do not cluster continuously. A colony here breaks cluster during mild spells, flies, and rears brood through much or all of the winter, and brood rearing is expensive. A mild winter can cost a colony more stores than a cold one. Regional extension guidance commonly gives a target in the neighborhood of a 100-pound total hive weight in late autumn, or 60 pounds and up of stored honey, with feeding indicated once reserves fall toward 40 pounds; treat these as starting points rather than answers.

The method for arriving at a local target is the examinable content. Weigh or consistently heft hives through several winters at the specific site. Record consumption across the season. Note the date the first dependable pollen and nectar actually arrive at that site, not the date a book gives. Set a target that

covers the observed consumption with a margin for a late spring. Then monitor through the winter anyway, and be prepared to feed - because the target is an average and the year in front of you is not.

7.9.2 Moisture is the winter problem here

A cluster generates heat and water vapor. Metabolizing honey produces water as a combustion product, and the colony adds more through respiration. In a cold climate the standard failure is that this vapor rises, meets the cold underside of the outer cover, condenses, and rains back down on the cluster. Wet bees at low temperature die fast, and chronic damp promotes fungal problems and rots the equipment.

In a humid southeastern winter the same physics operates with an important difference: the outside air is often already near saturation, so the colony cannot dump moisture into it as readily, and the temperature swings are wide, so condensation forms during cold nights and the hive never fully dries. The management response is a set of related measures that all move the moisture away from the cluster:

Upper ventilation. A small upper entrance, a notched inner cover, or a shim gives warm, moist air a path out at the top. This is not about keeping the colony cool; it is about letting vapor leave before it condenses. Note that this is a genuine point of disagreement in the craft: one school argues for a sealed, insulated top so that condensation forms on the walls rather than above the cluster - the "condensing hive" approach - and produces liquid water the bees can drink at the periphery. That approach works when the insulation is genuinely adequate; done halfway, in a humid climate, it produces a cold ceiling and a dripping cluster. Pick one model and implement it fully rather than mixing them.

A slight forward tilt. Raising the back of the hive perhaps half an inch to an inch means any water that does condense and run runs forward and out of the entrance rather than pooling on the bottom board under the cluster. It also sheds rain driven in at the entrance.

An insulated inner cover, or a moisture quilt. Insulation placed directly above the inner cover keeps the ceiling above the dew point, so vapor passes out through the upper vent instead of condensing on the coldest surface in the hive. An absorbent layer - a quilt box of wood shavings, or a rim filled with burlap or newspaper - does the same job by soaking the moisture up. Note the logic: **the insulation here is a moisture control, not a cold control.** That is the regionally correct way to think about it, and it is why "we do not need insulation in the south" is only half right.

Sound covers and an unshaded winter aspect. A leaking telescoping cover or a warped migratory cover puts far more water into a hive than the bees ever will. A winter site that gets morning sun helps the hive dry and encourages cleansing flights.

7.9.3 Emergency winter feeding: solid, not liquid

Liquid syrup is not a winter feed, and the reasoning is worth having in full because the exam states the opposite as a True/False trap.

Bees will not process syrup they cannot ripen. Below roughly the mid-50s degrees F, uptake becomes unreliable - the bees will not break cluster to reach a feeder, and syrup that is not taken sits and ferments. Even if taken, thin syrup is mostly water, and the colony must evaporate that water into an

already humid hive, which is an added burden at precisely the season when moisture is the hazard. Cold syrup also chills the bees that contact it. Entrance feeders in cold weather have the additional defect of being at the coldest point of the hive and of advertising themselves to robbers on any warm day.

The correct sequence is: complete all liquid feeding while temperatures still allow the bees to take it, ripen it and cap it. After that, emergency feed is **solid** - fondant, sugar cakes or candy boards, or the mountain-camp method of dry granulated sugar spread on newspaper over the top bars. Solid feed adds essentially no moisture, is available to the cluster without breaking it, and in the case of dry sugar over the cluster actually absorbs some of the hive's excess moisture in the process of being consumed.

7.9.4 Isolation starvation

The specific winter failure to recognize is a colony found with a small cluster on empty comb, with capped honey a frame or two away. The colony is not diseased and is not short of stores. It is starving because the cluster cannot cross cold comb to reach them. A cluster maintains itself by mutual contact and shared heat, and moving laterally across two frames of empty, cold comb in genuinely cold weather means peripheral bees chill and drop off faster than the cluster can advance. Movement in winter is overwhelmingly upward, into the warm zone the cluster itself has created, which is why honey directly above the cluster is available and honey beside it may not be.

The correct immediate action is to place solid feed - fondant, a sugar cake, or dry sugar - **directly above the cluster**, where the bees can reach it without moving laterally. If weather permits a brief manipulation, also move frames of capped honey in adjacent to the cluster or, better, position them directly above. Do not feed thin syrup, and do not conduct a full frame-by-frame inspection in cold weather; the information is not worth the heat you will cost the colony.

The follow-up question is the one that matters at master level: **why was the cluster too small to reach its own stores?** A cluster large enough to span several frames does not isolation-starve. A small midwinter cluster in this region traces back, more often than not, to inadequate late-summer mite control and consequent damage to the autumn bees. Treat isolation starvation as a symptom and go looking for the cause in the previous August.

7.9.5 The short or absent broodless window, and what it does to oxalic acid

Here is the regional fact that is most often stated backwards, and the exam states it backwards deliberately.

Oxalic acid in any formulation - dribble, vaporization, or extended-release strip - does not penetrate brood cappings. It kills mites on adult bees and does nothing to the mites reproducing inside sealed cells, which during active brood rearing is the large majority of the mite population. A single oxalic acid application is therefore highly effective against a broodless colony and only marginally useful against a colony with brood.

Northern beekeepers exploit this with a single midwinter application timed to a reliable broodless window, and it is one of the most efficient treatments in beekeeping. **In much of the southeastern US that window does not reliably exist.** Colonies here rear brood through most or all of the winter, and in the warmer coastal plain and Gulf coastal areas a colony may never be broodless at all. The claim that

southern colonies have a long dependable broodless period, and that adult-only treatments are therefore *more* dependable here, is exactly reversed: they are **less** dependable here, because the condition they depend on is usually absent.

That leaves three legitimate approaches, and a master-level candidate should be able to name all three.

Verify broodlessness rather than assuming it. Open the colony during the coldest stable stretch and look. If there is genuinely no sealed brood, a single application is worth taking. This is realistic in the southern Appalachians and at the northern edge of the piedmont in a cold year; it is unlikely on the Gulf coast.

Create the broodless window deliberately. Cage the queen, make a split, or requeen, producing a brood break, then apply oxalic acid while the last brood has emerged and before the new queen's brood is capped. This works, but it carries a cost that field work in the region makes concrete: Jack, van Santen and Ellis, working in a Gulf coastal climate and publishing in the *Journal of Economic Entomology* in 2020, found that 24-day queen caging severely reduced colony survival, and that adding oxalic acid vaporization at the then-label dose of 1 gram did not rescue the outcome. Brood interruption is not free, and a long interruption in a hot climate is expensive.

Work around the brood rather than through it. Repeated oxalic acid applications spread across a brood cycle catch mites as they emerge, and extended-release formulations do this by design. VarroxSan, registered in December 2023, is the only extended-release oxalic acid product currently registered in the US; it uses glycerin-impregnated strips that remain in the hive across a brood cycle, with label periods in the range of 42 to 56 days. WSU field trials conducted from 2021 through 2023 found it effective in fall and early summer applications with no significant oxalic acid residues in honey. This approach fits the region's biology better than a single application does, precisely because it does not require a broodless colony.

Two related notes. The registered oxalic acid products in the US are Api-Bioxal, Api-Bioxal RTU, EZ-OX and VarroxSan; the underlying acid is a commodity but the registration attaches to the product, and applying a non-registered material is a label violation. And on dose: work from Jack, van Santen and Ellis published in the *Journal of Apicultural Research* in 2021 found that vaporization at the then-current 1-gram label rate was ineffective, while 4 grams significantly reduced infestation without detectable harm to colonies or queens. On the strength of that work, EPA approved a 4-gram-per-brood-chamber vaporization rate on the Api-Bioxal label in June 2025, and the EZ-OX label now allows 2 to 4 grams. Always follow the current label of the specific product in hand.

7.10 Spring Dwindling

Spring dwindling is a colony that appeared to overwinter successfully and then declines sharply as winter ends, often collapsing in the weeks when its neighbors are building rapidly. In this region, because the build-up starts so early, it can appear startlingly early in the calendar - February in the coastal plain, when a northern beekeeper would not yet be looking.

The mechanism is demographic, and stating it as a race is the clearest way to hold it. The overwintered bees are reaching the end of their lives and dying at some rate; emerging brood is replacing them at

some other rate. If replacement exceeds mortality, the colony builds. If mortality exceeds replacement, it dwindles, and because the effect compounds - fewer nurse bees means less brood reared means fewer bees still - a colony that falls behind rarely catches up on its own.

Anything that suppresses brood rearing or accelerates adult mortality tips that balance:

- A failing or poorly mated queen, laying too few eggs.
- Poor early pollen availability, which caps the rate at which nurses can raise brood.
- *Vairimorpha (Nosema) ceranae*, which damages the midgut epithelium, shortens adult life and suppresses brood rearing.
- Residual mite and virus load, which shortens the lives of the very bees the colony is counting on to bridge to spring.
- Insufficient stores, which forces the colony to throttle brood rearing to conserve.
- Pesticide exposure damaging the adult population.

Diagnosis proceeds by eliminating these in order rather than by reflexive feeding. Check for eggs and assess brood pattern and quantity, which addresses the queen. Assess honey and pollen stores. Sample for *Nosema* if there is dysentery, crawling bees, or an unexplained adult loss. Take a mite count. And review the previous autumn's mite management - what was applied, when, and whether efficacy was verified - because in this region a dwindling colony in February very often traces directly back to a late or unverified treatment the preceding August. Act on the specific finding. A colony dwindling from a failed queen does not need syrup; it needs a queen or a combine.

7.11 Moving Colonies, and Pollination

7.11.1 Frame strength and what a contract has to specify

Colonies rented for pollination are assessed by **frame strength**, which means the number of frames covered by adult bees. It is a measure of population, and population determines foraging force, which is what the grower is actually buying. It is not hive weight, not the number of frames the box holds, and not the number of frames of sealed brood - though brood is a reasonable secondary specification, since brood drives pollen foraging.

Because a count of "frames covered with bees" depends heavily on when you look, the conditions of assessment belong in the contract. Bees are in the field on a warm afternoon and in the hive on a cool morning, so the same colony grades very differently at 8 a.m. and 2 p.m. A contract that specifies a strength standard without specifying an inspection temperature, time of day, method, who does the grading and how disputes are resolved has specified nothing enforceable.

A workable contract covers: the number of colonies and the price, potentially tiered by grade; the strength standard and the conditions and method of assessment, with an independent grader or an agreed sampling fraction; delivery and removal dates keyed to bloom stage rather than to fixed calendar dates; placement and access, including road conditions and gate keys; payment terms; pesticide

notification and application timing, which is where most disputes actually originate; liability for stings, vandalism and theft; and the resolution mechanism for a disagreement about strength. A beekeeper who cannot meet the standard should renegotiate before delivery rather than deliver substandard colonies and argue afterward.

7.11.2 The three-feet-or-three-miles problem

A colony must be moved 500 yards to another part of the same property. This looks trivial and is not.

The problem is that foragers navigate to the precise location of their hive, using landmarks and a memorized flight path fixed during orientation flights. Move the hive a few feet and returning foragers find the entrance anyway, drifting the short distance. Move it several miles and the hive is outside the range they know, so on their first flight from the new site they perform full orientation flights and re-learn the location. **The intermediate move is the problem case**: the new site is within familiar territory, so the bees do not reorient, and they fly back to the old location, mill about where the hive was, and are lost. In a 500-yard move you can lose most of the flying force.

Three solutions are standard, though the second suits only short moves:

Move it away and back. Relocate the colony more than about three miles for two to three weeks, so foragers reorient entirely, then bring it to the new site, where they reorient again. Reliable, and requires a second location.

Move it in stages. Shifting the hive a few feet a day, allowing the foragers to track it, works for moves of a few yards to a few tens of yards and needs no second site. For 500 yards it would take the better part of a year, so for a move of that length use one of the other two methods.

Move it directly and force reorientation. Place the hive at the new location and obstruct the entrance with leafy branches, a loose grass plug, or a similar partial barrier. Bees crawling out through an obstruction treat the exit as novel and perform orientation flights. Accept that you will still lose some foragers.

Whichever you use, a supplement worth knowing is to leave a nucleus or a swarm trap at the old location to collect the foragers that do return; they will join it and you can unite them with the parent later. Move in the evening or early morning when the flying force is home, and screen or close the entrance for the transport itself.

The underlying rule of thumb is **less than about three feet, or more than about three miles.** It is approximate, and the real variable is whether the new site falls inside the foragers' learned landscape, but it is the working form and it is what the exam expects.

7.11.3 Transport in warm weather: heat dominates everything

The principal physiological hazard when moving colonies in a closed or netted load in warm weather is **overheating**. The mechanism is that a colony cools itself by evaporating water and by fanning to move air through the hive, and a confined colony in a stationary or poorly ventilated load can do neither effectively. It has no water source, its foragers cannot fly for more, and the airflow it needs is blocked. Heat production rises as the disturbed colony becomes agitated, which makes matters worse. The result

is a runaway: comb softens, brood dies, comb can collapse under the weight of honey, and the colony can be lost within hours.

The mitigations follow directly from the mechanism. Provide ample screened ventilation and ensure airflow is genuinely unobstructed through the load, not merely present at the edges - netting over tightly stacked pallets blocks air. Travel at night or in cool conditions. Do not make long stops in the sun; if you must stop, stop in shade, and keep moving rather than idling. Secure the load against shifting, which both prevents comb damage and stops hives working loose. Remove very heavy honey supers, since heavy combs in a hot hive are what actually collapse. Unload promptly on arrival and provide water immediately. In the southeastern US the thermal risk dominates every other transport consideration for most of the year - chilling is not the concern, honey does not ferment in transit, and queen pheromone circulation is not disrupted by a truck ride.

7.12 Building a Local Bloom Calendar

Everything in this chapter is a regional approximation, and the master-level move is to replace it with a site-specific record.

Published regional calendars describe a broad area. Bloom timing shifts by a week or more for every degree of latitude and considerably more with elevation - sourwood at 3,500 feet and sourwood at 1,200 feet are weeks apart - and it shifts with land use, soil, aspect and the weather of the particular year. Worse, **bloom is not the same as nectar secretion.** A plant in full bloom secretes little or no nectar if soil moisture is inadequate, if nights are too cool, if it is too hot and dry, or if rain has washed the nectaries. Tulip poplar is notorious for this: the tree blooms on schedule and the flow fails. A calendar that records bloom dates alone will mislead you about what is actually available.

To build a usable local calendar:

Record the first, peak and last bloom dates of the major nectar and pollen plants within about two miles of the apiary - the practical foraging radius for the bulk of a colony's work - every year, so that you eventually have a range rather than a single observation.

Record the colors of incoming pollen at the entrance and work out which plants they correspond to. Pollen color is the most reliable cheap indicator you have of what the colony is actually working, as opposed to what is blooming nearby.

Keep hive weight records, ideally from a scale on one hive per yard and otherwise from consistent hefting notes. The weight trace is the direct measurement of nectar availability, and it separates a flow that happened from a bloom that did not produce.

Note when white new wax appears on the top bars and how quickly supers fill, both of which are behavioral evidence of a genuine flow.

And correlate the sequence with weather - accumulated warmth, rainfall, late freezes - rather than with fixed dates, so that in a year running two weeks early you can anticipate rather than discover it.

The most valuable output is not the list of flows. It is the **identification of the dearth periods**, because those are what determine feeding schedules, robbing precautions, the mite treatment windows, split timing and whether a fall crop is even worth supering for. A beekeeper who knows precisely when his forage fails is managing the region's actual hazard.

7.13 Numbers to Know Cold

Figure	Value	Why it is that value
First substantial pollen, coastal plain	January (red maple)	Red maple blooms in the coldest part of the year here; pollen, not temperature, releases the brood-rearing constraint
First substantial pollen, piedmont	Late January to February	Same trigger, a few weeks later with latitude and elevation
Swarm inspections begin, coastal plain	Mid-to-late February	Colonies reach swarming condition a month or more ahead of northern practice
Swarm inspections begin, piedmont	Early-to-mid March	Build-up follows the maple and willow pollen by about four weeks
Swarm inspections begin, mountains	Late March to April	Elevation delays the whole sequence
Swarm inspection interval	7 days	Egg to sealed queen cell is 8 days and the swarm leaves at capping; 7 days guarantees no cell is missed
Main flow, piedmont	Mid-April to mid-May (tulip poplar)	The region's principal surplus crop
Sourwood flow	Late June into July, higher elevations	The mountain varietal; narrow and weather-dependent
Tupelo flow	Early to mid spring (about late March to early May), specific river swamps	Ogeechee tupelo has a very narrow bloom in a limited range
Midsummer dearth	Roughly late June through August	Between the end of the spring flow and the goldenrod bloom
Autumn flow	Mid-September into October	Goldenrod and aster; nutritional rather than commercial value
Brood nest temperature	About 95 degrees F	Sets the metabolic cost of brood rearing, which is why late winter is the hungriest period
1:1 syrup	Equal parts sugar and water by weight	Approximates nectar; stimulates brood rearing, wax secretion and comb drawing
2:1 syrup	Two parts sugar to one part water by weight	More carbohydrate per unit water, so it is stored quickly with little evaporative cost; the autumn feed

Figure	Value	Why it is that value
Lower limit for liquid feeding	Roughly the mid-50s degrees F	Below this, uptake is unreliable, syrup ferments in the feeder, and added moisture burdens the colony
Late-autumn hive weight target, region	About 100 pounds total, or 60-plus pounds of stores	A regional starting point only; the real figure is measured at the site
Feeding trigger in late winter	Reserves falling toward 40 pounds	Consumption peaks as brood rearing resumes and stores are already drawn down
Northern comparison for winter stores	80 to 90 pounds of honey	Longer, colder winter with continuous clustering; the southeastern figure is lower but not proportionally so
Small hive beetle egg to larva	About 2-3 days	Eggs hatch quickly, so an unpatrolled patty becomes a larval infestation between two weekly inspections
Small hive beetle larval feeding	About 10 to 14 days	The window in which comb is destroyed; then larvae leave to pupate
Small hive beetle soil pupation	3 to 5 weeks, longer when cool	Sets the generation interval and explains repeated waves through a warm season
Winter bee lifespan	4 to 6 months, versus 5 to 6 weeks for summer bees	Fat body and vitellogenin reserves; this is the tissue *Varroa* feeds on
Late-summer mite decision window	Late July to early September, by region (coastal plain, piedmont, mountains)	Treatment must be complete before the winter bee cohort is reared
Post-treatment verification count	Promptly at the end of the labeled treatment period	The only way to detect a product that failed, now essential given amitraz resistance
Y215H amitraz-resistance mutation frequency	100 percent of 39 mites screened (2026)	Up from about 66 percent in earlier surveys; treating without verifying is treating blind
VarroxSan label period	Roughly 42 to 56 days	Long enough to span a brood cycle, since oxalic acid does not penetrate cappings
US annual colony losses	55.1 percent (2023-24); 55.6 percent (2024-25); 39.9 percent (2025-26, preliminary)	Beekeeper-acceptable loss is 15 to 20 percent; the gap is what splitting and requeening pay for
Hive move rule of thumb	Under about 3 feet, or over about 3 miles	Foragers navigate to a precise location; intermediate moves strand them
Re-siting interval for a short move	2 to 3 weeks away, then return	Long enough for the learned location to be replaced
Winter hive tilt	Half an inch to an inch, front lower	Condensate and driven rain run out of the entrance rather than pooling under the cluster

Figure	Value	Why it is that value
Practical foraging radius for calendar purposes	About 2 miles	The bulk of a colony's foraging, which is what a site calendar needs to describe

7.14 Common Misconceptions

Misconception: Winter is the dangerous season in the southeastern US, the same as everywhere else. **Correction:** The midsummer dearth is. It combines zero forage with maximum temperature, peak mite populations, peak beetle pressure, maximum robbing pressure, and a colony from which the beekeeper has just removed the honey. Winter here is mild; what kills in winter is usually damage inflicted in August.

Misconception: Weekly swarm inspections start in April, once the colonies have built up and the flow is on. **Correction:** Swarm cells can appear in the coastal plain by late February and in the piedmont in March, with peak swarming in April and May. The cell goes from egg to capped in eight days and the swarm leaves at capping, so inspections that wait for the peak find hives already empty. The manipulations that prevent swarming must be prepared in winter, because they have to be performed before the colony decides.

Misconception: Colonies in the south have a nice long broodless period in midwinter, so a single oxalic acid treatment is more dependable here than up north. **Correction:** Exactly reversed. Colonies in most of the region rear brood through most or all of winter and may never be broodless. Oxalic acid does not penetrate cappings, so single applications are *less* dependable here. Broodlessness has to be verified, created deliberately, or worked around with repeated or extended-release applications.

Misconception: Reversing brood boxes in late winter is a standard annual operation; do it on a set date. **Correction:** It is conditional on where the brood actually is. Reverse when the cluster has moved into the top box and the bottom is empty. Do not reverse when brood spans both boxes, because our late winter alternates warm spells with hard freezes and a divided brood nest chills. When in doubt, add space above instead.

Misconception: Goldenrod is the fall honey crop, so super for it and harvest it. **Correction:** Its dominant value in this region is nutritional. The late pollen is what allows the colony to rear well-provisioned winter bees. A poor autumn bloom is a signal that protein supplementation may be needed, not a lost sales opportunity.

Misconception: A protein patty is good for any struggling colony. **Correction:** In this region a patty on a colony too weak to patrol it is a small hive beetle nursery. Feed protein in small portions matched to a few days' consumption, remove the paper backing, place it directly over the cluster, and do not feed it to a weak colony at all. Every feeding decision here is also a beetle decision.

Misconception: The colony looked strong in September, so the mite treatment worked. **Correction:** A colony with a heavy mite load looks excellent in September, because its summer bees are still alive and healthy. The damage is to the pupae that will become winter bees. Appearance is the least reliable

evidence available at exactly the moment the decision is made; only a mite count tells you anything, and a post-treatment count is what tells you the product worked.

Misconception: Amitraz is reliable, so a strip treatment in August settles the mite question. **Correction:** Every mite in a 2026 screen of the loss event carried the Y215H resistance mutation, in operations that had relied on amitraz. A treatment that is not verified by a follow-up count may be no treatment at all, and the beekeeper will not know until the colony dies in January.

Misconception: Feed thin syrup through the winter; the bees take it when they can get to it. **Correction:** Bees do not process syrup they cannot ripen. Below about the mid-50s degrees F uptake is unreliable, syrup standing in a feeder ferments, and the water content is itself a burden on a clustered colony in a humid winter. Finish liquid feeding while it can be ripened and capped; after that, use fondant, sugar cakes or dry sugar directly over the cluster.

Misconception: A small cluster sitting on empty comb in January is diseased. **Correction:** It is almost certainly isolation starvation - the cluster cannot cross cold comb to reach honey a frame or two away. Put solid feed directly above it and, if the weather allows, move capped honey adjacent or above. The real question is why the cluster was so small, and the answer usually points back to the previous August's mite management.

Misconception: Southeastern hives should be wrapped and insulated like northern ones, just less so. **Correction:** Cold is not the regional threat; moisture is. Upper ventilation, a slight forward tilt, sound covers and an insulated inner cover that keeps the ceiling above the dew point matter far more than wrapping. Insulation here is a condensation control, not a warmth control - which is the reason it is worth using at all.

Misconception: Leave the queen excluder on all winter; it keeps the brood nest where you want it. **Correction:** The winter cluster moves upward as it eats the stores above it. If the queen cannot follow through the excluder she is left behind and dies. It is not about brittleness, ventilation or regulation. Remove it, or ensure the queen is above it before winter.

Misconception: Equalize the yard every spring by moving brood from the strong hives into the weak ones. **Correction:** That distributes foulbrood spores, viruses, *Nosema* and mites through the whole apiary, and it props up colonies whose weakness has a cause that brood does not address. Diagnose first, take brood only from verified-healthy donors, and do not weaken the donor.

Misconception: Splitting during the dearth is fine; it is the same operation as a spring split. **Correction:** A small colony in July has no forage, cannot defend its entrance against robbers, cannot patrol its comb against beetles, and must mate a queen in extreme heat. Dearth splits need feeding and beetle protection and fail at a much higher rate. Split in spring, or wait until the goldenrod.

Misconception: A 500-yard move within the same property is close enough that the bees will sort it out. **Correction:** That is precisely the distance that loses your foraging force. The new site is inside the foragers' learned landscape, so they do not reorient, and they return to the empty original location. Move under three feet or over three miles, or use a forced reorientation (a staged move is practical only for short distances).

Misconception: Hefting tells you whether a colony is queenright or how it is doing generally. **Correction:** It estimates stored honey, and therefore whether feeding is needed, without opening the hive in weather where opening it would cost heat. That is all it does, and it is worth a great deal because it lets you check stores in February, which is exactly when the colony is spending fastest.

7.15 Self-Check Questions

- Describe the shape of the southeastern beekeeping year, naming the major periods of surplus, the principal dearth, and the character of winter. Then name the two features that most distinguish this calendar from a northern one and say what each implies for management.
- Explain why pollen availability rather than temperature or day length is the effective trigger for the late-winter build-up, and explain why February and March are the hungriest months of the year for a colony in this region.
- Your apiary is in the coastal plain. State when you would begin seven-day swarm inspections, justify the seven-day interval with a number, and list what must already be done before that date for the inspections to be useful.
- A colony on a heavy tulip poplar flow has a brood nest packed with nectar and a queen with almost nowhere to lay. Name the condition, explain the mechanism by which it both restricts the queen and promotes swarming, describe your response, and say how you would distinguish it from a failing queen.
- Give four distinct objectives that a spring split achieves simultaneously, then explain what a split costs and why the southeastern season makes routine splitting practical when a short-season climate does not.
- List at least five distinct risks created by the midsummer dearth, and for each give the mechanism that makes the dearth the cause.
- Explain why late summer is the most consequential monitoring point in the management year. Your answer must include the physiological mechanism, and must explain why a colony that looks excellent in September can be dead in January.
- A beekeeper applied amitraz strips in early August as he has for ten years and did not count afterward. State what could be wrong, cite the relevant evidence, and describe the protocol that would have detected it.
- Distinguish 1:1 from 2:1 syrup in composition and purpose, give two cautions about feeding syrup, and state what you would feed instead in January and why.
- A colony in the coastal plain has never been observed broodless. Describe three legitimate approaches to using oxalic acid in that colony, and identify the cost associated with one of them.
- Explain the mechanism of condensation in a winter hive and describe four measures that address it. Explain specifically why insulation is used in a mild-winter region.

- A colony found in January has a small cluster on empty comb with capped honey two frames away. State the diagnosis, the immediate action, what you would not do, and the follow-up question you should be asking.
- A beekeeper asks how many pounds of honey to leave for winter here. Explain why no single figure answers the question and describe the method for arriving at a local target.
- A colony must be moved 500 yards within the same property. Explain the problem in terms of bee navigation and give three solutions plus one supplementary measure.

7.16 Self-Check Answers

- An early build-up beginning in mid-to-late winter as red maple, willow, henbit and the early fruit bloom supply the first substantial pollen. A main surplus flow in spring on tulip poplar, blackberry and dewberry, clover, holly, black locust and privet, with gallberry adding a coastal plain flow slightly later, tupelo giving a narrow high-value crop in certain river swamps, and sourwood a mountain flow in early summer. A pronounced dearth through the hottest part of summer. A modest autumn flow on goldenrod and aster whose value is chiefly nutritional. A mild winter with little or no true broodless period. The two distinguishing features are how early spring begins, which advances swarm season by a month or more and forces winter equipment preparation, and the severity of the midsummer dearth, which drives robbing, starvation, beetle pressure and mite build-up while northern colonies are still storing surplus.
- Nurse bees must eat pollen to develop hypopharyngeal glands and secrete larval jelly; stored beebread is a depleting reserve, so the rate of brood rearing is capped by protein supply, not by ambient temperature. Red maple in January or February lifts that cap, and the brood nest expands. February and March are the hungriest months because the brood nest must be held near 95 degrees F regardless of outside temperature, so a colony rearing brood on six frames burns stores several times faster than a clustered broodless one - and it is doing that against stores drawn down all winter, before the main flow has arrived. Mild spells make it worse, because the colony breaks cluster, flies unproductively and rears more brood.
- Mid-to-late February. Seven days because a queen cell goes from egg to capped in eight days and the prime swarm leaves at or just after capping, so a seven-day cycle cannot miss a cell in its destroyable, open state. Before that date I need supers assembled and drawn comb pulled from storage and checked for wax moth, nucleus boxes and bottom boards built, queens ordered from a regional producer, swarm traps already deployed, and a decision made about which manipulation I will use - split, Demaree, or opening the brood nest - because all of them require equipment on hand at the moment of the inspection, not a week later.
- The colony is honey-bound. Foragers deposit nectar in the nearest available cells; when storage above is insufficient or undrawn, the available cells are those in the brood nest as brood emerges, so the nest is progressively backfilled. That restricts the queen physically, reducing both her laying and the comb area over which she leaves footprint pheromone, and it produces the congested, nectar-packed nest the colony reads as a reproductive signal. Respond by adding storage space immediately, preferring drawn comb to foundation, and by restoring laying space directly with empty drawn frames inserted in the nest or by lifting nectar-filled frames into a super. Check the excluder is sound. The distinction from a failing queen is what occupies the

cells: honey-bound means full combs of the wrong thing with a healthy queen; a failing queen leaves cells empty or fills them spottily.

- It controls swarming by removing the population and brood that generate the impulse; it makes increase; it replaces expected losses, which nationally have run near 40 to 56 percent annually against a beekeeper-acceptable 15 to 20 percent; and it creates a brood break in the queenless half that strands mites on adults where a single-application treatment reaches them (the half with the laying queen breaks only if that queen is also caged or removed). It costs surplus, because a colony's maintenance cost does not halve when its population does, so one very large colony out-produces two medium ones on the same flow. The long southeastern season makes it practical because both halves have time to build to wintering strength, which they would not in a short-season climate.

- Starvation, because a large colony consumes several pounds a week with nothing coming in, and the beekeeper has just removed the supers. Robbing, because foragers with nothing to collect probe other entrances and recruit, and a weak colony can be stripped in hours. Small hive beetle takeover, because beetles are at their seasonal peak while colonies contract, so comb goes unpatrolled and beetles lay in it. Varroa reaching its annual maximum, because mite numbers have compounded all season while the adult bee population is now falling, so mites per 100 bees rises on both ends of the ratio. Heat stress and absconding, because cooling depends on evaporation and an unshaded hive without water cannot keep up. And queen supersedure or reduced laying, because nurse bees short of protein feed the queen less.

- The bees reared in late summer and early autumn are the overwintering cohort, and they differ physiologically from summer bees in having large fat bodies and high vitellogenin, which is what gives them a four-to-six-month lifespan. *Varroa* feeding drains the fat body system - hemolymph in the pupa, the fat body itself in the adult - so a parasitized pupa emerges with a compromised fat body, reduced vitellogenin and usually a viral infection, most importantly deformed wing virus, and its lifespan is shortened. The bee looks normal. A colony in September still has its healthy summer population and therefore looks strong, but the bees it needs for February are already damaged, and they die two or three months early - which is why the colony is found dead in midwinter with stores still in the hive.

- Amitraz resistance. In the 2026 *PLOS Pathogens* investigation of the 2024-25 loss event, all 39 mites screened carried the Y215H mutation in the Octbeta2R octopamine receptor gene, up from roughly 66 percent in earlier regional surveys, in operations that had been relying on amitraz. Without a follow-up count he may be running a completely uncontrolled mite population while believing the colony is treated. The protocol is a pre-treatment count, the full labeled treatment period, and a second count promptly at the end of that period. If the number has not fallen, the product failed and there is still time in the season to use something else - but only for a beekeeper who looked.

- 1:1 is roughly equal parts sugar and water by weight, close to nectar in concentration, and functions as a stimulative feed that encourages brood rearing, wax secretion and comb drawing; it belongs in late winter and spring and when drawing foundation. 2:1 is roughly two parts sugar to one of water, supplying more carbohydrate per unit water, so the bees expend less energy evaporating it and can store it fast; it belongs in autumn when the object is winter stores. Cautions: never feed syrup with saleable honey supers on the hive, since stored syrup extracted as honey is adulteration; and use plain white granulated sugar in warm rather than boiling

water, without acid inversion, because heating sugar solutions generates HMF, which harms bees. In January I would feed fondant, sugar cakes or dry sugar directly over the cluster, because below about the mid-50s degrees F bees will not reliably take or ripen syrup, and the added moisture is a burden in a humid winter.

- First, verify rather than assume: open the colony in the coldest stable period and look for sealed brood, and if there genuinely is none, take the single application. In the coastal plain this will usually fail. Second, create the window deliberately by caging the queen, splitting or requeening, then treat in the gap. The cost is real: regional field work by Jack, van Santen and Ellis published in 2020 found that 24-day queen caging severely reduced colony survival, and adding oxalic acid vaporization at the then-label 1-gram rate did not rescue it. Third, work around the brood with repeated applications across a brood cycle or with an extended-release product - VarroxSan, the only registered extended-release oxalic acid product in the US, with label periods in the range of 42 to 56 days, which is designed for exactly this situation.

- The cluster metabolizes honey, producing water as a combustion product, and adds more through respiration. Warm moist air rises, meets the cold underside of the outer cover, condenses and drips back onto the cluster; wet bees at low temperature die quickly. In a humid winter the outside air is often near saturation, so the colony cannot shed vapor easily and the hive never dries. Measures: upper ventilation, so vapor leaves before it condenses; a half-inch to one-inch forward tilt, so condensate and driven rain run out of the entrance rather than pooling under the cluster; an insulated inner cover or moisture quilt; and sound, unwarped covers. Insulation is used here not to keep the bees warm but to hold the ceiling above the dew point so vapor exits through the vent rather than condensing on the coldest surface in the hive.

- Isolation starvation: the colony has stores but the cluster cannot cross cold empty comb to reach them, because peripheral bees chill and drop off faster than the cluster can advance laterally, and winter movement is predominantly upward into the warm zone the cluster has created. The immediate action is solid feed - fondant, a sugar cake or dry sugar - placed directly above the cluster, and if the weather permits a brief manipulation, capped honey moved adjacent or above. I would not feed thin syrup, which adds moisture the colony must evaporate and may not be taken at all, and I would not do a full frame-by-frame inspection in the cold. The follow-up question is why the cluster was small enough to be trapped, which in this region usually traces to inadequate or unverified late-summer mite control.

- Because the requirement is total metabolic demand over the interval between the end of autumn forage and the return of reliable spring forage, and that varies with location and elevation, colony size and configuration, hive type and exposure, stock, and how early the first dependable pollen arrives. Southeastern colonies need less than upper-Midwest colonies, but not proportionally less, because they break cluster and rear brood during mild spells and so consume faster than a continuously clustered colony of the same size. The method is to weigh or consistently heft hives across several winters at the specific site, record consumption, note the actual arrival date of the first reliable forage there, set a target covering observed consumption with a margin for a late spring, then monitor through the winter and be ready to feed anyway.

- Foragers navigate to a precise location learned on orientation flights. Under about three feet they simply find the entrance; over about three miles they are outside the familiar landscape and reorient fully on their first flight from the new site. At 500 yards the new site is inside the

landscape they know, so they do not reorient and instead return to the empty original location and are lost. Solutions: move the colony more than three miles away for two to three weeks and then bring it to the new site; move it a few feet at a time over successive days, which suits moves of a few yards to a few tens of yards but would take most of a year at 500 yards; or move it directly and obstruct the entrance with leafy branches so that emerging bees treat the exit as novel and reorient, accepting some loss. As a supplement, leave a nucleus or a trap at the old site to collect the foragers that do return.

7.17 Further Reading

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- Clemson Cooperative Extension, Home and Garden Information Center: fact sheets on seasonal apiary management and regional honey plants.
- University of Florida IFAS Honey Bee Research and Extension Laboratory: publications on autumn and winter feeding, small hive beetle, absconding and oxalic acid.
- NC State Extension Apiculture Program: *The Small Hive Beetle: A Pest of Honey Bee Colonies*, and seasonal management publications for the piedmont and coastal plain.
- Auburn University and the Alabama Cooperative Extension System: beekeeping publications and the US Beekeeping Survey, which reports the annual colony loss figures cited in this chapter.
- LSU AgCenter and the USDA-ARS Honey Bee Breeding, Genetics and Physiology Laboratory, Baton Rouge: Gulf coastal management, small hive beetle and stock resources.
- Mississippi State University Extension Service, *Managing Varroa Mites in Honey Bee Colonies*: seasonal thresholds expressed in mites per colony as well as percentage infestation.

Chapter 8. Nutrition, Feeding & Pollination

Covers exam questions Q140-Q158.

8.1 Orientation

Three ideas organize everything in this chapter, and almost every master-level item here is one of them in disguise.

The first is that a colony runs on two separate currencies and cannot convert between them. Carbohydrate comes from nectar and honey; protein, lipids, sterols, vitamins and minerals come from pollen. A colony with eighty pounds of honey and no beebread will stop rearing brood, and no amount of syrup will restart it. The reverse also holds. This is why the question “is the colony fed?” is always two questions, and why a beekeeper who answers only the carbohydrate half is guessing.

The second is that quality and diversity of the protein source matter more than the mass of it. A pollen is not a generic protein; it is a particular amino acid profile with a particular sterol and lipid content, and bees cannot synthesize sterols at all. A landscape carrying one enormous bloom can be nutritionally poorer than a scruffy roadside with fifteen. The same logic condemns crude protein as a way of judging a pollen substitute: nitrogen content tells you nothing about whether the limiting amino acid is present, whether a sterol source is there, or whether the bees will eat the thing.

The third is that feeding and pollination are the same subject viewed from two ends. Feeding is what a beekeeper does when the landscape does not supply the colony. Pollination is what a beekeeper sells when a grower’s landscape does not supply the crop. Both are about the fit between a colony’s requirement and a place’s capacity, and the professional obligations in a pollination contract - strength, timing, placement, pesticide communication - are simply the nutritional and toxicological facts written down and signed.

The examiner is probing whether you can reason from mechanism. Why does intake rate peak at an intermediate nectar concentration rather than rising to saturation? Why does liquid feeding fail below a particular temperature rather than simply becoming slower? Why does a substitute with excellent laboratory protein numbers produce declining brood over eight weeks? Why are colonies delivered at the opening of bloom rather than a fortnight early? Each of these has an answer in physiology or physics, and the answer is the point.

8.2 The Two Currencies: Carbohydrate and Protein

Nectar and honey supply carbohydrate, which the colony burns. Flight, thermoregulation, wax secretion, comb building and the simple maintenance metabolism of tens of thousands of bees are all paid for in sugar. Over a year a colony consumes on the order of 120 to 175 pounds of honey equivalent, though published estimates vary widely with climate, colony size and how the accounting is done. What the beekeeper harvests is the surplus above that, which is why a mediocre flow can produce a colony in fine condition and no crop at all.

Pollen supplies everything else: protein, lipids, sterols, vitamins and minerals. A colony collects somewhere between about 33 and 55 pounds of pollen in a year in most temperate accounting, with published figures ranging from roughly 22 to well over 100 pounds depending on colony size, season length and whether a trap was fitted. The wide range should not trouble you; the useful fact is the order of magnitude and the fact that the requirement scales with brood rearing, not with adult population.

The conversion is where the mechanism lives. Protein does not go from beebread to larva directly. Nurse bees eat beebread, digest it, and convert it in the hypopharyngeal glands into brood food. A worker larva is fed a secretion, not a pellet of pollen. The direct pollen consumption of a worker larva is small - on the order of 5 milligrams - but the nurse bees supporting her consume far more, roughly 65 milligrams of pollen apiece across the nursing period. Accounted at colony level, rearing one worker to emergence costs on the order of 125 to 190 milligrams of pollen, or 25 to 38 milligrams of usable protein. A colony rearing 1,500 bees a day is spending roughly half a pound of pollen a day (about 190 to 285 grams), every day, and the beebread arc around the brood is the visible balance in that account.

That accounting explains the two failure modes a beekeeper actually sees. A colony short of carbohydrate starves outright and fast, sometimes within a day or two of the last cell emptying. A colony short of protein does not starve; it shrinks. Brood rearing contracts, the queen keeps laying but eggs are removed, young larvae are cannibalized, and the adult population ages without replacement. The second failure is slower, quieter, and much more often missed.

8.2.1 Ten amino acids and one thing bees cannot make

De Groot's work in the early 1950s established that honey bees require ten essential amino acids in the diet: arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. They are essential in the technical sense - the bee cannot synthesize them and must eat them. De Groot also established the proportions, which matter as much as the presence, because protein utilization is governed by the amino acid in shortest supply relative to requirement. Leucine carries the largest single requirement, roughly a sixth of total essential amino acid need. Which amino acid is in shortest supply depends on the feedstuff, so it has to be worked out by comparing each ingredient, and the finished blend, against de Groot's proportions.

The second dietary absolute is sterols. Bees cannot synthesize sterols from acetate the way vertebrates do. Every molecule of sterol in a bee's membranes and every molecule of moulting hormone precursor came from pollen. The dominant sterol in honey bee tissue is 24-methylenecholesterol, which makes up something like 60 to 70 percent of pupal sterol; beta-sitosterol, isofucosterol, campesterol, desmosterol and cholesterol make up most of the rest. Work published in 2025 using an engineered strain of the yeast *Yarrowia lipolytica* to supply this sterol mixture is the clearest demonstration of the point: colonies fed an otherwise complete artificial diet without those sterols essentially ceased producing viable brood over about three months, while colonies fed the same diet with the sterols carried larvae and capped brood through to the end of the trial. Guidance now circulating puts an adequate dietary level of 24-methylenecholesterol at roughly half a percent of diet dry weight.

This is the mechanism behind an observation every beekeeper who has fed substitute for a whole season has made: the patty works for a few weeks and then stops working. Protein reserves in the bees

and residual beebread carry the colony through the early period. As those run out, the sterol deficit begins to bite, and brood rearing declines even though the label protein figure has not changed. It is also the honest reason no substitute fully replaces diverse natural pollen over long periods.

8.2.2 Lipids, vitamins, minerals

Pollen lipid content runs from about 1 percent to nearly 20 percent and is not incidental. Foraging preference in bees tracks the protein-to-lipid ratio of pollen rather than protein content alone, which tells you the bees are managing a ratio and not maximizing a single nutrient. Practical formulation guidance puts crude lipid in a supplemental diet at roughly 5 to 8 percent alongside 23 to 30 percent crude protein. Pollen also supplies the B vitamins, ascorbic acid, and the minerals - potassium, phosphorus, magnesium, calcium, iron and trace elements. None of these is present in sugar syrup in any meaningful amount, which is the whole reason the first idea in this chapter is true.

8.3 Why Pollen Diversity Matters More Than Pollen Quantity

Pollens differ enormously. Crude protein among bee-collected pollens spans roughly 2 to 60 percent, with most useful sources in the 15 to 30 percent band. Amino acid profiles differ independently of that: a pollen can be high in protein and still limiting in one essential amino acid, in which case the surplus of the others is deaminated and burned as carbohydrate. Lipid content and sterol composition vary again independently.

The consequence is statistical. A colony taking pollen from a dozen sources is very unlikely to be short in any one amino acid, because the deficiency of one source is covered by the surplus of another. A colony taking pollen from one source is entirely at the mercy of that source’s profile. This is why the experimental result matters, though it is more nuanced than often stated: bees fed a polyfloral pollen blend showed higher glucose oxidase activity, an immune measure, than bees fed single-source pollens, including richer ones (Alaux et al. 2010), and under Nosema challenge a polyfloral blend gave survival as good as the best high-protein single pollen and better than poorer ones (Di Pasquale et al. 2013). Those authors concluded that pollen quality matters most, and that diversity is the practical insurance against any single source being poor. Diversity is doing something quantity cannot.

The practical translation is that forage quality is assessed on diversity as well as abundance. A section of intensively farmed land carrying one enormous crop bloom can be nutritionally poor for the six weeks on either side of that bloom and nutritionally narrow during it. A landscape of mixed woodland edge, old pasture, river bottom and unmowed margin can look unimpressive and feed colonies far better. It is why the recommendations that follow - site for a succession of blooms, negotiate mowing timing, leave margins, encourage cover crops - are nutrition recommendations rather than aesthetic ones.

One error worth killing now: bees do not tire of a pollen and stop collecting it out of boredom. They will work a single abundant source hard for as long as it yields. The problem with monotony is nutritional, not motivational, and the colony gives no behavioral warning that it is heading into a deficiency.

8.4 Beebread: What Happens to Pollen After It Lands in the Cell

A returning forager packs her corbicular loads into a cell. House bees then pack the pellets down with the head, add regurgitated nectar or honey and glandular secretion, and the cell is eventually topped with a film of honey. The stored product is beebread, and it differs chemically and microbiologically from the pollen that went in.

The dominant chemical change is acidification. Lactic acid bacteria, notably *Apilactobacillus kunkeei* (formerly *Lactobacillus kunkeei*) and relatives, metabolize the sugars added with the nectar and produce lactic acid. The pH of stored pollen falls steadily over roughly the first week after packing, from around 6 to roughly 4.0 to 4.3. At that acidity, the moulds and spoilage organisms that would otherwise destroy a moist, protein-rich, sugar-rich mass at 95 degrees F cannot grow. The beebread is pickled.

The reason to be precise about this is that the craft literature routinely overstates it. Bacterial abundance in stored pollen spikes in the first day or two and then falls sharply as the acidity rises - exactly the opposite of what you would see if microbes were progressively digesting the pollen for the bees. The evidence supports preservation rather than predigestion. The acid environment is produced substantially by non-microbial additions of nectar, honey and glandular secretions, with the bacteria contributing rather than driving. A master-level answer says beebread is preserved by acidification, in which lactic acid fermentation participates, and does not claim that microbes predigest the pollen or that beebread is nutritionally superior to fresh pollen because of fermentation. On that last point the evidence runs the other way: nurse bees preferentially consume fresher stored pollen, and stored pollen loses nutritional value with time.

Three practical consequences follow. Beebread stored over winter is worth less in spring than its volume suggests, which is part of why late-winter protein feeding pays even in colonies that look provisioned. Combs of beebread stored outside the hive, without bees to maintain them, spoil or are destroyed by wax moth and beetle and are difficult to keep well. And the acidification is why a pollen substitute patty, which has none of this protection, is a growth medium: it goes sour, moulds, or becomes a nursery for something worse.

8.5 The Hypopharyngeal Gland, Brood Food, and Vitellogenin

The link between what a colony eats and what it can rear runs through a pair of glands in the worker's head.

A newly emerged worker has small, undeveloped hypopharyngeal glands. Given beebread in the first days of adult life, the acini enlarge dramatically and begin secreting the protein-rich component of brood food. Gland size peaks in the nursing period, roughly days six through twelve, then regresses as the bee transitions to foraging, at which point the same glands switch to secreting the invertase used in nectar processing. The gland is therefore a direct readout of protein status: bees reared and fed under protein stress develop smaller glands, secrete less, and rear fewer larvae. Measuring hypopharyngeal gland acinus size is one of the standard laboratory assays of diet quality for exactly this reason.

The same protein intake builds the other reserve that matters. Vitellogenin is a large glycolipoprotein - about 180 kilodaltons in the honey bee - synthesized in the fat body and circulating in the haemolymph.

In most insects it is purely a yolk precursor for the reproductive female. In the honey bee it has been co-opted into a general storage and regulatory protein in workers. It is the substrate drawn on for brood food synthesis. It is an antioxidant, mopping up the oxidative damage that otherwise accumulates in a long-lived cell. It suppresses the transition to foraging by interacting antagonistically with juvenile hormone, so a bee with high vitellogenin titre stays in the nest and stays young. And it is the physiological definition of a winter bee.

That last point is the one the exam cares about. A winter bee is not a genetically different bee; she is a bee reared in autumn, on adequate pollen, with little brood to feed, who therefore accumulates and retains a high vitellogenin titre and a large fat body and lives for months rather than weeks. Take the autumn pollen away and you get bees with low vitellogenin that behave physiologically like summer bees. They will not last the winter, and the colony dwindles in late winter without ever having been obviously sick. This is the mechanism behind the rule that the autumn pollen flow determines winter survival. In the southeastern US that means the goldenrod and aster bloom of late summer and autumn is not a honey crop question, it is a survival question, and a poor one is the strongest indication for protein feeding that the calendar offers.

8.6 Reading a Colony's Nutritional Status in the Field

Assessing stored beebread is a routine part of inspection that is routinely skipped. The single best indicator that a colony is short of protein is little or no beebread in and around the brood area, combined with brood rearing that has contracted despite warm weather and a laying queen present. That combination - empty cells available, queen present and capable, brood area shrinking - points at protein and almost nothing else.

The discrimination that separates a competent inspection from a careless one is between a pollen dearth and a pollen-bound brood nest. Both reduce brood area. In a dearth, the cells around the brood are empty and available and the queen has room she is not using because there is no protein to support larvae in it. In a pollen-bound nest, the combs are packed solid with beebread, often wall to wall across the frames flanking the brood and creeping into the brood combs themselves, and the queen has nowhere to lay. The remedies are opposite. The dearth wants feeding. The pollen-bound nest wants laying space - removing and replacing the packed frames, giving drawn comb, or reversing to put empty comb where the queen can reach it. Feeding a pollen-bound colony makes it worse.

Other indicators are weaker and should not be leaned on. Drone presence tracks season and colony condition generally, not protein specifically; colonies do evict drones under stress but also under dearth of any kind and on the ordinary autumn schedule. Low surplus honey has a dozen causes. Bearding is thermoregulation and congestion. None of these is a protein test.

8.6.1 Starvation, which is the other failure and is faster

The carbohydrate failure has its own signature, and it is worth being able to recite because starvation kills within a day or two once it starts.

Hefting is the first test and the most useful: a colony short of stores is conspicuously light at the back edge. Opened, it shows no capped stores and no nectar in the combs. Brood is being removed or

cannibalized. The classic sign is dead bees head-first and deep in empty cells, having died reaching for the last food; find that and you are looking at a colony that starved, not one that absconded or was robbed out. Bees may be lethargic, unable to fly, or trembling. The cluster is small and tight with nothing adjacent to move onto. In warm weather, a colony approaching starvation becomes unusually defensive and its neighbors begin robbing, so an outbreak of robbing in a yard is a signal to check weights everywhere, not just at the hive being robbed.

The immediate action is feed, now, by whatever route conditions permit. Warm enough for the bees to take and process liquid, feed syrup. Cold, feed solid: fondant, a sugar cake, or dry sugar laid on newspaper directly above the cluster where the bees are, not at the far end of the box where they cannot reach it. Best of all, if you have one and you know the source colony's health status, give a frame of capped honey placed immediately adjacent to the cluster. Speed matters more than elegance. In the southeastern US the two windows in which this happens are the midsummer dearth, especially in the week or two after supers come off, and late winter, when brood rearing has resumed and consumption has risen sharply against stores that were adequate in December.

8.7 Judging a Pollen Substitute

A pollen supplement contains natural pollen; a pollen substitute contains none. The distinction matters for disease risk, since pollen of unknown origin can carry pathogens, and irradiated pollen is the safer input where supplements are used at all.

Crude protein is the figure printed on the bag and it is the worst single criterion available. Crude protein is a nitrogen determination multiplied by a conversion factor. It tells you how much nitrogen is in the product. It tells you nothing about whether that nitrogen is arranged into a profile the bee can use. A diet at 35 percent crude protein that is limiting in isoleucine has the biological value of a diet with the isoleucine content and a great deal of wasted nitrogen, because utilization is capped by the scarcest essential amino acid and the excess is deaminated and excreted. Two products with identical labels can perform completely differently.

A master-level assessment adds at least these criteria:

Amino acid profile, and specifically which amino acid is first limiting. This requires knowing the de Groot proportions and comparing. Common feedstuffs - soy flour, brewer's and torula yeast, casein, various protein isolates - differ in which amino acid runs short, so the comparison has to be made for each ingredient and for the blend.

Sterol content and source. The bee cannot make sterols. A diet without an adequate sterol source will support brood rearing for weeks on residual body and comb reserves and then fail, and the failure will look like something else.

Lipid content and the protein-to-lipid ratio. Foraging preference tracks the ratio, not protein alone, and a fat-free high-protein diet is poorly matched to what bees actually select.

Palatability and measured consumption under field conditions. An uneaten patty has a biological value of zero regardless of its composition. Consumption is measurable - weigh the patty in, weigh the remainder out, and you have a number. It is the criterion most easily obtained and least often collected.

Digestibility and freedom from antinutritional or toxic components. Some plant proteins carry protease inhibitors and other antinutritional factors; some sugars and additives are poorly tolerated. Raw soy is a classic example of a material that must be processed before it is fit to feed.

The definitive test is not a laboratory analysis at all. It is a feeding trial measuring brood area produced per unit of substitute consumed, run against a control, over a long enough period that the sterol effect has time to show. Anything shorter measures palatability and residual reserves.

8.7.1 When to feed protein in this region, and how

There are three reliable windows in the southeastern US, and each has a different reason.

The midsummer dearth, roughly from the end of the main flow through to the autumn bloom, is the first. Little pollen is coming in, the colony is still rearing brood, and stored beebread is being drawn down and often exhausted. Feed here to hold brood rearing through the gap and to avoid entering autumn with an aged, unreplaced population.

Autumn, when the goldenrod and aster bloom is poor, is the second and the most consequential. This is the window that sets winter bee quality through the vitellogenin mechanism described above. A dry autumn that shortens or thins the aster bloom is the strongest single indication for protein feeding in the region's calendar, and the consequences show up not in November but in February.

Late winter, when stimulating early build-up ahead of the main flow or ahead of a pollination contract, is the third. At that point brood rearing is limited by protein rather than by carbohydrate - the red maple and willow bloom may have started but is weather-dependent and easily interrupted - and protein feeding moves the build-up curve forward. The colony you need in March is built in January.

A fourth case arises wherever colonies are placed on a crop that supplies a narrow and nutritionally poor pollen for an extended period. The crop may be pouring pollen in; if it is one pollen, the deficiency logic of the previous section applies.

The important caveat, and one candidates often miss: a colony with abundant natural pollen coming in will frequently ignore a patty entirely. Bees prefer natural pollen and will leave a substitute untouched while a flow is on. Feeding protein during a good pollen flow costs money and gains nothing, and the uneaten patty becomes a liability.

8.7.2 Patty sizing in small hive beetle country

That liability is specific and serious in the southeastern US. A pollen patty is a warm, moist, protein-rich mass sitting on top of the brood nest. It is an excellent small hive beetle oviposition site and an excellent larval food. A large patty left in place for three weeks in a colony that is not eating it does not feed bees; it produces beetles, and a beetle-slimed hive is a far worse outcome than the mild protein shortage you were treating.

The management is portion control and turnover. Feed small - a quarter to a half of a standard patty at a time rather than a whole one, sized so the colony consumes it in about a week. Place it over the brood nest where the bees are dense enough to patrol it, not off to one side on a cold outer frame. Check at every visit, replace what has been eaten, and remove what has not. If a colony has stopped eating patty, stop feeding it patty. If the colony is too weak to patrol the patty, it is too weak to be given one; fix the strength problem first. Some beekeepers in the region strip the paper entirely and feed a small dollop directly on the top bars so there is no paper layer for beetles to hide under; others use dry protein in an open feeder outside the hive during warm weather, which removes the in-hive beetle risk altogether at the cost of the disadvantages of open feeding discussed below.

8.8 Sugar Syrup: Ratios, Chemistry, and What Each Is For

The two standard ratios are 1:1 and 2:1, both by weight, and the distinction is not arbitrary.

1:1 syrup is one part sugar to one part water by weight, which is roughly 50 percent sugar by weight. That puts it in the same concentration band as a good nectar. The colony treats it as a nectar flow: foragers recruit to it, house bees process it, wax glands come on, comb is drawn, and the queen is stimulated to lay. Its purpose is stimulation - spring build-up, drawing foundation, supporting a nucleus or a package, feeding a colony being pushed for an early contract. It is not an efficient way to put weight on a colony, because roughly half of what you carry to the yard is water the bees must then evaporate.

2:1 syrup is two parts sugar to one part water by weight, about 67 percent sugar. That is close enough to honey that the bees need to remove comparatively little water to cure it, so it goes into storage fast and with less effort. Its purpose is provisioning - autumn feeding to bring a colony up to overwintering weight, emergency provisioning of a light colony while the weather still permits. Because it is thick, it does not stimulate brood rearing the way light syrup does, which in autumn is a feature rather than a defect: you want stores laid down, not a late round of brood eating them.

A useful working figure is that a gallon of 2:1 syrup adds roughly seven to nine pounds to a colony's stores once cured. Target weights vary with climate. In the southeastern US, regional guidance commonly targets 60 pounds or more of stored honey (about 100 pounds total hive weight) going into winter, with feeding indicated once reserves fall toward 40 pounds (Chapter 7), against 80 to 90 pounds in the north. The regional figure is lower not because the winter is easier on stores in a simple sense but because it is shorter and interrupted by flyable, foraging days - and it is deceptive, because brood rearing resumes early here and consumption in February can exceed consumption in December.

8.8.1 Why liquid feeding fails in the cold

Below a certain temperature syrup feeding does not merely slow down; it stops working and starts causing harm. Two mechanisms are at work.

The first is access. Bees in a winter cluster do not break it to travel to a feeder. A frame feeder at the side of the box or a jar over an inner cover hole a few inches off the cluster is simply unreachable, and a colony can starve within reach of a full feeder.

The second is ripening. Taking syrup is only half the job; the colony must evaporate it down to roughly 17 or 18 percent moisture to store it. Evaporation requires active fanning and warm air moving through the nest. In cold weather the colony is contracting, not ventilating, and the added moisture cannot be driven off. Uncured syrup sits in the combs, ferments, and adds water vapor to a nest where condensation is already the main winter killer in the form of cold water dripping onto the cluster.

The published thresholds cluster around 50 to 57 degrees F as a daytime cutoff for liquid feeding. Different extension sources favor different ends of the band, and the higher figure is argued on the grounds of ripening rather than access. The honest answer is that this is a band, not a line, and that the transition occurs earlier than most beekeepers expect. The practical rule for the southeastern US: once daytime highs are consistently below the mid-50s degrees F, stop feeding syrup and switch to solids, and understand that you have therefore lost the ability to add stores in any quantity. Autumn feeding is a job with a deadline.

8.8.2 Solids: fondant, sugar cakes, and dry sugar

Above the cluster, in cold weather, the bees can reach a solid and consume it without needing to cure anything.

Fondant is a fine-crystal sucrose paste, usually made with some glucose syrup, and enough moisture that bees can eat it directly. It is the best choice for a weak colony, because it requires no added water.

Sugar cakes - granulated sugar moistened, pressed and dried into a slab - are cheap and easy to make and work well in a colony strong enough to generate the humidity that dissolves them.

Dry sugar, poured on newspaper over the top bars or onto a shim, is the crudest and the cheapest. Bees will not store dry sugar and will eat it only when they must, so it functions as an emergency ration rather than a feeding program. It requires water to dissolve, which in a winter hive comes from condensation on the inner cover - the same condensation that would otherwise drip onto the cluster, which is why the mountain camp method is both a feed and a moisture management tactic. Do not rely on dry sugar in a weak colony that cannot reliably obtain water.

All three go directly over the cluster. A solid feed at the far end of a box is a solid feed the colony will die next to.

8.8.3 Hydroxymethylfurfural, and the rules that follow from it

Hydroxymethylfurfural, HMF, forms when sugar solutions are heated, particularly under acid conditions, and accumulates over time in warm storage. It is a degradation product of hexoses - fructose is more prone to it than glucose - and at elevated concentration it is toxic to bees, damaging the gut epithelium and shortening life.

The numbers are worth carrying, with the caveat that the literature is not unanimous. Practical feeding guidance commonly puts 30 parts per million as the level above which HMF in bee feed should be regarded as harmful. A 2022 European risk assessment derived a reference point equivalent to roughly 42 milligrams per kilogram of feed for a 20-day exposure, and - because the toxicity is time-reinforced and winter bees live for months - adjusted that down to about 15 milligrams per kilogram for a 180-day

exposure. In laboratory dose-response work, 30 milligrams per kilogram did not significantly raise mortality, 150 milligrams per kilogram raised 20-day mortality to nearly 60 percent, and 750 milligrams per kilogram was nearly lethal to all. Some field studies found no colony-level harm at up to 150 milligrams per kilogram. The defensible position is that the margin is comfortable for short summer feeding and narrow for winter feeding, because a winter bee is exposed for six months rather than three weeks.

Formation is a matter of temperature and time. Honey or syrup held at about 86 degrees F accumulates significant HMF over roughly 250 days; at 122 degrees F, over about 10 days; at 158 degrees F, over about 10 hours. A drum of syrup on a trailer in July is in the second regime, not the first.

The practical rules follow directly and should be stated as rules:

- Dissolve sugar in hot but not boiling water, and never boil syrup.
- Do not invert syrup with acid. The old practice of adding cream of tartar or vinegar to "help the bees" accelerates exactly the reaction that produces HMF, and bees invert sucrose perfectly well themselves with their own invertase.
- Store syrup cool and use it promptly. Syrup is not a shelf-stable commodity.
- Treat high-fructose corn syrup with particular care, because its fructose content makes it more prone to HMF formation and because it is typically bought in bulk and stored, which is the condition that produces the problem.
- If you are feeding for winter, the margin for error is smaller than it is in summer.

The same chemistry underlies HMF's use as a quality index in honey, where an elevated figure indicates heat abuse or age, a subject taken up in the honey chemistry chapter.

8.8.4 Feeding honey: a biosecurity rule people break

Feeding honey of unknown origin to bees, including retail honey, is a recognized route for introducing American foulbrood. *Paenibacillus larvae* spores remain viable in honey for decades - the classic figure is at least 35 years and the practical assumption is indefinitely. Retail honey is frequently blended from many sources in many countries, any of which may have had foulbrood, and nothing in ordinary processing kills the spores. A jar of crystallized supermarket honey fed to a nucleus is a plausible route for introducing a notifiable disease into an apiary that had none.

Feeding back honey from one's own colonies is a different proposition, but only if the health status of the source colony is known. Honey from a deadout of unexplained cause is not known. The rule is: feed honey only from colonies you have inspected and judged clean, and never feed honey you bought.

This is one of the most consistently repeated rules in beekeeping and one of the most consistently ignored, usually by someone who does not want to waste an old jar.

8.8.5 Feeding and the honey crop: an adulteration problem entirely within your control

Honey is defined - by the FDA's 2018 labeling guidance and by the Codex standard - as the natural sweet substance produced by honey bees from the nectar of plants or from honeydew. A product containing stored sugar syrup is not honey. If a colony is fed while supers intended for harvest are on the hive, it may store that syrup in those supers, and selling the result as honey is adulteration and misbranding. The FDA guidance is styled as nonbinding recommendations, but the misbranding provisions of the underlying statute are not, and state labeling law sits on top.

The operating rule is simple and admits no exceptions worth making: remove supers intended for harvest before feeding. If an emergency compels feeding during a flow - a sudden dearth with colonies about to starve - keep the resulting stores out of the harvested crop by marking those supers and leaving them on the colony, or by extracting them separately and using the product as bee feed. This is both a legal and an ethical matter, and unlike most of the risks in beekeeping it is entirely under the beekeeper's control.

8.9 Feeders and Their Failure Modes

Every feeder is a compromise among capacity, disturbance, robbing risk, drowning risk and cost. In the southeastern US, where the midsummer dearth is severe and robbing pressure during it is intense, robbing risk dominates the choice, and that argues heavily for internal feeders.

Feeder	Principal advantage	Principal drawback
Entrance (Boardman)	Trivially simple; syrup level visible without opening the hive	Sits at the entrance, where it advertises feed to every colony in the yard and readily provokes robbing; heats in sun; tiny capacity
Frame or division board	Substantial volume inside the hive, out of sight of robbers	Requires opening the hive to refill; drowns bees without a ladder, float or roughened surface
Hive-top	Large capacity, refilled with minimal disturbance, well protected from robbing	Adds height and considerable weight; can drown bees at the access slot; harbors beetles and mould if not cleaned
Inverted pail or jar over the inner cover hole	Cheap, effective, feeding rate set by hole size and count, no drowning	Limited capacity; needs an empty box or eke around it; can leak if the vacuum breaks in the sun
Bag or ziplock on the top bars	Very cheap, no drowning, minimal robbing risk	Single use, awkward, leaks, attracts small hive beetles under the plastic
Open or barrel feeding away from the yard	Fast for many colonies at once; no hive opening at all	Feeds strong colonies preferentially, transmits disease among colonies and apiaries, and triggers apiary-wide robbing

Two of these deserve elaboration because the exam asks about them.

Drowning is a mechanical problem with a mechanical solution. A bee that falls into syrup and cannot get purchase on a smooth vertical wall drowns. Frame feeders need a ladder, a float, a piece of hardware cloth or a handful of straw; hive-top feeders need a screened access and a rough surface; pail and jar feeders avoid the problem entirely because the bees never contact a free surface, which is one reason they remain popular for small operations.

Open feeding is the one the exam will press. Syrup in a communal container away from the hives is fast and requires no hive manipulation, and some commercial operators use it deliberately in particular situations. For most beekeepers it is a poor choice for three reasons that compound. It distributes feed in proportion to foraging force, so the strong colonies you were not worried about take most of it and the weak colonies you were feeding get least - exactly backwards. It mixes bees from many colonies at one point, which is an efficient way to move *Paenibacillus larvae* spores, *Vairimorpha (Nosema)* spores, viruses and small hive beetles between colonies that would otherwise have no contact. And it teaches every colony in the neighborhood that free sugar is available in the open air, which sets off robbing behavior that does not politely stop when the barrel is empty. It also draws bees from neighboring apiaries, which compounds the disease problem and is likely to be resented. A few jurisdictions restrict or prohibit it outright.

It is not illegal under federal law, and it does not destroy bees' ability to find natural forage - both are distractor claims. The objection is the three practical ones.

8.9.1 Robbing, generally

Whatever feeder you use, the discipline around it matters as much as its design. Feed at dusk rather than midday so that the flying force is settling rather than mobilizing. Do not spill syrup; wipe up what you spill. Reduce entrances on weak colonies before you start feeding, not after robbing begins. Keep hive openings short in dearth. Feed all colonies in a yard at once rather than a few, so you are not creating a single conspicuously rich target. And recognize that a robbing outbreak is self-reinforcing: once it starts, the smell of exposed honey recruits more robbers, and the usual end of a serious episode is a dead colony, a spread of disease and a set of beekeepers wondering what happened.

8.10 Nectar Concentration, Viscosity, and Why the Optimum Is in the Middle

Here is a genuinely mechanical question, and one candidates get wrong by reasoning from preference rather than physics.

Foragers do prefer more concentrated nectar, all else equal, and will abandon a dilute source for a concentrated one. But it does not follow that energy intake rate rises monotonically with concentration. Energy intake rate is the product of two terms: the sugar concentration of the solution, and the volumetric rate at which the bee can get the solution into her crop. The first rises with concentration. The second falls with concentration, and it falls steeply, because viscosity rises far faster than concentration does - roughly exponentially over the range that matters.

Multiply a rising linear term by a steeply falling one and you get a curve with an interior maximum. Energy intake rate peaks at an intermediate concentration and declines on either side. Below the peak

the bee is efficiently drinking mostly water; above it she is struggling to move treacle through a proboscis.

The location of the peak depends on how the animal drinks. For suction feeders - butterflies, hummingbirds - the modeled optimum is around 33 percent sugar. For viscous dippers, which lap nectar up on a hairy tongue, the optimum is around 52 percent. Honey bees do both, switching between lapping and suction depending on the nectar, which puts their effective optimum in the region of roughly 50 to 65 percent. The comparative ecology follows: flowers pollinated by bees offer nectar averaging around 35 percent sugar, while those pollinated by hummingbirds and butterflies offer 20 to 25 percent. The plants are matched to their pollinators' fluid mechanics.

Three practical consequences. First, in hot dry weather nectar in exposed flowers concentrates by evaporation, and bees will abandon a source that has become too thick even though it is richer in sugar than it was in the morning - a puzzling observation until you know why. Second, very heavy syrup is taken more slowly than beekeepers expect, so the intuition that thicker syrup must mean faster feeding is wrong; 2:1 syrup is preferred in autumn because it needs less curing, not because it is taken faster. Third, the peak being interior is why nectar concentration in the low-to-middle 50s is the sweet spot for feeding when speed of uptake is what you care about.

8.11 Water: A Year-Round Requirement

Water serves at least three distinct colony functions, and the exam wants all of them.

Evaporative cooling. In hot weather, water collectors deposit droplets in the nest and on the combs, and fanning bees drive evaporation that pulls heat out. A large colony in a southeastern summer can collect a quart or more of water a day for this purpose alone. This is why water demand spikes in the heat and why an apiary without a reliable source in July becomes a nuisance complaint at somebody's swimming pool.

Dilution of concentrated or crystallized stores. Honey is roughly 17 percent water and beebread is a dry paste. To feed larvae and to feed themselves, bees dilute stores with water. When stores have crystallized - and honey from some sources crystallizes hard in the comb - dilution is the only way to use them. This is also why a colony fed dry sugar needs water access: without it, the sugar is just gravel.

Maintenance of brood nest humidity. Brood develops in a narrow humidity band as well as a narrow temperature band, and desiccation of eggs and young larvae is a real failure mode in dry conditions.

All three operate, and their relative weight shifts with season. The reason water is a year-round requirement rather than a summer one has a regional twist: in the southeastern US, brood rearing resumes in mid to late winter, which means the dilution and humidity demands arrive in January and February, well before the cooling demand. On the first mild day of the year a colony will be flying for water, and if it is flying in January the only water source in the neighborhood may be a neighbor's pool or a livestock trough.

Establishing a source before the bees establish their own is far easier than redirecting them afterward. Bees are strongly site-faithful to water sources; once a colony has recruited to a swimming pool, moving

it takes persistent effort and sometimes does not work. Provide standing water with landing surfaces - stones, floats, a board - in a sunny spot near the yard, keep it from going dry, and put it out before the first flight of the year. Bees show a preference for water with some dissolved mineral and organic content over distilled clean water, which is why they favor livestock troughs and puddles; a source that is slightly “dirty” is more likely to hold them than a clean one. That preference is not, however, a nutritional requirement in the sense of replacing pollen-derived minerals; the primary functions are the three above.

8.12 Forage, Carrying Capacity, and What a Beekeeper Can Actually Change

Here candour is a professional obligation, because the popular answer is wrong and a master-level beekeeper will be asked about it publicly.

What a beekeeper can do. Choose apiary sites by the forage calendar of the surrounding landscape rather than by convenience, looking for a succession of blooms and a diversity of sources rather than one impressive crop. Negotiate with the landowner about management that costs them little and matters to bees - delaying a mowing until after a bloom, leaving field margins and ditch banks unmown, planting a cover crop that flowers, not spraying a “weed” that happens to be the best August source on the property. Plant supplemental forage aimed specifically at the gaps in the local calendar rather than at the times when bloom is already abundant; in this region, that means midsummer. Provide reliable water. And - the most important and least discussed - do not overstock a site.

What a beekeeper cannot do. A beekeeper cannot meaningfully feed colonies from their own planting. A colony forages over several square miles; the classic dance-decoding work put the median foraging distance at a little over a mile (about 1.7 km) but the range out past six miles, with the area exploited routinely covering dozens of square miles over a season. An acre of pollinator planting is a rounding error against that. A half-acre of bee-friendly flowers is a lovely thing that benefits native bees, which forage over hundreds of meters rather than miles, and it is a token for a honey bee colony. A beekeeper also cannot increase the amount of nectar a plant secretes. Secretion is set by species and genotype, by weather - temperature, humidity, and above all soil moisture - and by soil. This is why the same tulip poplar stand yields a crop one year and nothing the next, and why nothing you do to the stand changes that.

The honest advice to a new beekeeper is therefore that site selection matters far more than planting, and that a pollinator garden is a good thing to do for reasons other than feeding an apiary. Saying otherwise is popular and dishonest.

8.12.1 Carrying capacity

Apiary carrying capacity is the number of colonies a location can support without forage competition depressing per-colony productivity and condition. It is set by the abundance, diversity and timing of forage within flight range, and it is not a fixed property of a site: it varies between years with rainfall and with what the neighbors do to their land, and it varies within a year because a site that is generous in April may be barren in July.

It is not a legal limit, not a property of a hive stand, and not a statement about how many colonies one person can inspect in a day - those are all plausible-sounding distractors for something quite different.

Two facts make carrying capacity a management problem rather than a curiosity. First, exceeding it does not kill colonies dramatically; it quietly reduces every colony at the site, so a beekeeper who doubles the colonies on a yard and sees total yield rise by a third concludes that the site had room when in fact each colony is doing worse. Second, competition is invisible from inside the yard. Other beekeepers' colonies within flight range compete just as effectively as your own, and you may have no idea they are there.

The defensible way to estimate it is empirical and incremental. Place a small number of colonies at the site with hive scales or at least a disciplined weight record, and run them for a season. Survey the landscape within roughly a three-mile radius for major nectar and pollen sources and their bloom periods - this is a map exercise and a driving exercise, and it is what separates a beekeeper who knows a site from one who has merely used it. Ascertain whether other apiaries are present, by asking around and by checking the state apiary registry where one exists. Then scale up in steps, watching per-colony yield and per-colony condition rather than yard totals, and stop when the per-colony figures start to fall. Continuous hive weight monitoring makes this much easier than it used to be, because it turns an impression into a time series.

8.13 Pollination I: Per-Visit Efficiency versus Overall Effectiveness

Two measures are constantly confused and the exam separates them.

Per-visit pollinator efficiency is how much a single visit to a single flower accomplishes: pollen grains deposited on a receptive stigma, or fruit set achieved per visit. It is a property of the insect's behavior and morphology in relation to that flower - where it contacts the anthers and stigma, whether it is hairy in the right places, whether it grooms pollen away before contacting the next flower, whether it moves between plants or works one plant.

Overall pollination effectiveness at the crop level is the product of per-visit efficiency and the number of visits delivered. Visits delivered depends on the number of foragers present, how long they forage each day, how early in the morning they start, how they tolerate cool or overcast weather, and - decisively for agriculture - whether they can be delivered to the field at all.

Honey bees are frequently mediocre on the first measure. For particular crops - blueberry, squash and other buzz-pollinated or specialist-served flowers - a specialized native bee deposits more pollen per visit, and native bees generally work earlier and colder and move between plants more freely. The large comparative analysis published in 2013 across 600 fields and 41 crop systems found that wild insect visitation increased fruit set in every system studied while honey bee visitation did so in only about 14 percent, and that an equivalent increase in wild insect visitation raised fruit set about twice as much as an increase in honey bee visitation. Strikingly, in that dataset an increase in honey bee visitation raised pollen deposition on stigmas about 74 percent more strongly than the same increase in wild insect visitation - the honey bee deficit was in the fruit set that pollen produced, which points to the quality of transfer, particularly cross-pollination, rather than the quantity moved.

Honey bees dominate commercial pollination anyway, and the reason is the second term. No other pollinator can be delivered by the tens of thousands per acre, on a date chosen by the grower, to a field that has no resident pollinator population because it is forty acres of one crop in a landscape of forty-acre fields. Manageability, transportability, timing control and sheer number are the honey bee's contribution, and in large-scale monoculture they swamp per-visit differences.

The corollary is the examinable part. Where per-visit efficiency is not merely lower but near zero for a particular mechanism, numerical advantage cannot fully compensate. That is the case for crops requiring sonication.

8.13.1 Poricidal anthers and why honey bees cannot buzz pollinate

Some plant families - the nightshades and the heaths prominent among them - hold pollen in anthers that do not split open. Instead the anther is a tube with a small pore at the tip, and pollen leaves only if the anther is shaken hard enough to bounce the grains out. Tomato, eggplant, cranberry and blueberry all have this arrangement (in tomato the fused anther cone works the same way).

The behavior that extracts it is sonication, or buzz pollination. A bumble bee grasps the anther with her mandibles, curls her body around it, uncouples her wings from the indirect flight muscles, and contracts those muscles at high frequency. The thorax vibrates at a few hundred hertz - bumble bee sonication runs around 400 hertz, against a honey bee wingbeat of roughly 220 to 250 hertz - and the pollen fires out of the pore in a visible puff. The sound is a distinctive high whine quite unlike flight.

Honey bees do not do this. The interesting point is that it does not appear to be an anatomical impossibility: honey bees can vibrate their thoracic muscles at high frequency for other purposes, including the vibration signal and shivering thermogenesis. They simply do not perform the behavior on flowers. Whatever the evolutionary explanation, the practical fact is settled - honey bees are not buzz pollinators.

Honey bees still visit blueberry and tomato, chiefly for nectar, and in doing so brush against anthers and stigmas and effect some pollination, particularly on varieties with looser anthers or in the presence of wind. The standard commercial response is high stocking density, which raises the number of low-efficiency visits until the aggregate is adequate. Rabbiteye blueberry in the southeastern US is the regional case: growers commonly combine honey bee stocking at high rates with managed bumble bees where the economics justify them and with habitat management supporting the native southeastern blueberry bee and other wild species, which are far more efficient per visit on those flowers.

A beekeeper offering pollination should be able to say all of this to a grower plainly. It is a better professional position than overselling, and the grower who is told honestly where honey bees excel and where they supplement is the grower who comes back.

The distractor explanations are worth naming so they can be rejected: honey bees can perceive these flowers perfectly well, the nectar is not toxic, and the flowers do not close by mid-morning. The mechanism is vibration and nothing else.

8.14 Pollination II: Contracts, Strength Standards, and Verification

A pollination agreement should be written. Not because beekeepers and growers are dishonest, but because the disputes that arise are always about the same handful of things, and the handful is short enough to write down in a page.

8.14.1 The terms that belong in a contract

Colony strength standard, and the method, timing and conditions of its assessment. The single most disputed item. Specify the standard as a number of frames of bees, an average across the delivered set, and a floor below which an individual colony is not counted. Specify who assesses, what fraction is sampled, and under what conditions - see below, because conditions change the answer.

Number of colonies and the stocking rate per acre. State both, because the rate is what the grower is actually buying and the count is what gets delivered.

Delivery and removal dates, keyed to bloom stage rather than the calendar. Bloom moves with the season; a calendar date set in November is a guess. “Delivered at the opening of bloom, removed at petal fall on the latest variety” is enforceable and correct.

Placement locations, drop sites, and access arrangements. Where the pallets go, who opens the gate, whether a loaded truck can reach the drop after rain, who is responsible if it cannot.

Price per colony, payment terms, and the adjustment for colonies failing the standard. Say what happens to a light colony: replaced, discounted, or not paid for. A contract that sets a standard and no consequence has not set a standard.

Pesticide undertakings. Advance notification of any application, restrictions on what may be applied while bees are present and at what time of day, and disclosure of tank mixes and adjuvants. This is the term most often omitted and most often regretted.

Responsibility for water provision. A colony in an orchard needs water and there may be none. Say who supplies it.

Liability, insurance, and damage. Damage to colonies from equipment, livestock, vandalism or spray; damage by bees to third parties; who carries what insurance.

Dispute resolution. How disagreements about strength or performance will be settled and by whom, agreed in advance when nobody is angry.

Each of these protects both parties, which is the point worth making in an exam answer. The grower is protected against weak colonies, late delivery and early removal; the beekeeper is protected against being sprayed out, being blamed for a poor set that had nothing to do with bees, and being unable to retrieve colonies from a flooded field. A term that protects only one side tends not to survive the second season of a relationship.

8.14.2 How strength is actually verified

Strength is assessed as frames of bees. A frame of bees means a frame with bees covering it, and the standard interpretation is that a frame counted as one is covered on both sides top to bottom; partial coverage is summed - two frames half-covered count as one.

The assessment conditions are not a technicality, because the same colonies grade differently under different conditions, and in opposite directions.

Grade too cold and the bees are in a tight cluster spanning fewer frames than the population would otherwise occupy, and the colony undergrades. Grade at midday in warm weather and a large fraction of the population is out foraging, so the bees in the box undergrade the colony's real force. The awkward truth is that both errors run the same way, and a beekeeper whose colonies are graded carelessly generally loses.

The practical resolution is to grade when the cluster is expanded but flight is limited: early morning before substantial flight begins, or on an overcast, cool-but-not-cold day, with the working guidance being a temperature warm enough that bees are spread across the frames rather than balled - commonly given as above about 60 degrees F - while the flying force is still at home. The assessment method matters too. Looking down into an open box from above undercounts badly, because much of the population is on the frame undersides and in the lower box. The reliable method is to tip the boxes off the bottom board and off each other and look at the undersides of the frames as well as the top bars, counting what is actually there.

Sampling is normally a fraction rather than a census - ten percent of the delivered colonies, randomly selected, is the common standard - and the assessment is best done by an independent third party, with the contract saying who pays. A great many disputes come down to an inspector who is not a beekeeper, so specifying the assessor's qualifications is worth a sentence.

For reference, the best-documented standard in North American pollination is the almond contract, which typically requires an eight-frame average with a six-frame minimum, with colonies below the minimum not counted or paid at a reduced rate, and with grading conducted on a ten percent sample after delivery and before full bloom. Fees track strength: recent contract ranges run roughly from the high 170s per colony for a four-to-six frame average up to the low 200s for a ten-to-twelve frame average, with the market average in the region of 200 dollars. The most recent federal survey of pollination costs, covering 2025, put the average almond price at 209 dollars per colony against 54 to 87 dollars for apples, 20 to 86 dollars for blueberries depending on region, 71 to 114 dollars for watermelons, 74 to 79 dollars for cantaloupes and 77 to 84 dollars for cranberries, with about 1.63 million colonies used for almond pollination alone that year (the all-crop total for the two western survey regions was about 1.87 million). Those numbers move, and a candidate should quote them as a snapshot rather than a constant, but the shape - almonds far above everything else, and a wide regional spread within a single crop - is stable.

8.14.3 A colony strength standard is not only a frame count

Frames of bees is the contractible number, but a grower is buying foragers on the crop and a competent beekeeper knows what else produces them. The colony needs a laying queen, verified by the presence of eggs. It needs substantial brood, because open brood is the strongest single stimulus to pollen foraging, and pollen foragers are the ones that contact anthers. And it needs somewhere to put what it collects, because a honey-bound colony curtails foraging and a congested colony makes swarm preparations in the middle of a contract. Nine or ten frames of bees with six to eight frames of brood and empty comb above is a different animal from ten frames of bees with no brood, even though both grade the same.

8.15 Pollination III: Stocking Rates, Placement, and Timing

8.15.1 Stocking rates

Stocking rate is the number of colonies per acre. Recommendations vary substantially among extension sources and among varieties within a crop, and a candidate should quote a range and know what moves it.

Crop	Commonly recommended colonies per acre	What moves the number
Almond	2	Variety self-incompatibility; density of plantings; self-fertile varieties reduce it
Apple	1 to 2, up to 3 for difficult varieties	Bloom density, variety compatibility, weather during a short bloom window
Rabbiteye and highbush blueberry	3 to 5, with a literature average near 4 and some recommendations to 8	Poricidal anthers and low per-visit efficiency; presence of native bumble bees and the southeastern blueberry bee
Watermelon	1 to 3, literature average near 1.3	Seedless triploid varieties need far more pollen transfer; morning-only receptivity
Cantaloupe	1 to 3, literature average near 2.4	Very short stigma receptivity, sometimes minutes in heat
Cucumber	1 to 3, literature average near 2	Gynoecious varieties with dense female bloom need large populations
Squash and pumpkin	About 1	Native squash bees often do the work where they are abundant
Strawberry	1 to 2	Multiple visits per flower needed for well-formed fruit

Three principles sit behind the table. First, rate rises as per-visit efficiency falls, which is why blueberry carries the highest rates in the region. Second, rate rises when the receptive window is short, because the same number of visits must be delivered in less time. Third, rate rises when the crop is a poor competitor for bee attention - a crop with unattractive nectar surrounded by attractive wild bloom needs more colonies than one that is the only thing flowering.

8.15.2 Placement within the field

Distribution matters more than total count in crops where foraging range within the field is short. Colonies concentrated at one corner of a large block give visitation that declines with distance from the drop. The standard practice is multiple smaller drops distributed through the planting rather than one large one, sited on firm ground with truck access, facing so that flight paths do not cross roads, work areas or property lines, in morning sun where possible so colonies warm early and start foraging early - which is decisive for crops like watermelon and cantaloupe whose stigmas are receptive only in the morning. Colonies should be off the ground on pallets or stands, away from irrigation and from the spray-equipment fill site, and where possible near a water source or supplied with one.

8.15.3 Timing: why colonies arrive as bloom opens

Colonies are usually delivered at the beginning of bloom, commonly at around 5 to 25 percent bloom, rather than well in advance. The reason is forager fidelity, and it is worth stating as a mechanism rather than a rule.

A colony placed in a field a week before the target crop opens does not wait. Its scouts find whatever is flowering within flight range - the wild bloom on the field margins, a competing crop, a wood edge - and recruitment builds a foraging force committed to those sources. Foragers are strongly faithful to a source they have been working successfully, so when the target crop opens, a substantial part of the force is still commuting to the competitor. A colony that arrives as the crop opens finds the crop to be the most abundant resource in range and orients onto it. You are exploiting the recruitment system's bias toward whatever is most rewarding at the moment of arrival.

The 5 to 25 percent figure is a compromise. Arrive too early and you get the fidelity problem. Arrive too late and you lose the early part of a bloom that may only last ten days, and you give the colonies no time to settle, orient and resume normal foraging after the disturbance of a move. Enough open flower to hold the bees, not so much that the crop is half over, is the target.

There are real exceptions, and knowing them is the master-level part. Where the crop is the overwhelming dominant forage with no competitor within range - a very large block in an intensively farmed landscape at a season when nothing else is out - the fidelity argument loses most of its force and early placement costs little. Where access roads become impassable once the spring rains arrive, a beekeeper may have to get colonies in early or not at all, which is a genuine consideration in the southeastern US on heavy soils. And where the grower needs colonies present for a bloom that will open unpredictably with the weather, arriving a few days early is cheaper than missing the opening.

Removal is the mirror image. Colonies come out at petal fall on the latest-blooming variety, because after that the field is a dearth with a pesticide program about to start, and leaving colonies in a post-bloom orchard is asking to have them sprayed.

8.16 Pesticide Communication and the Obligations on Both Sides

The pesticide term is where a pollination relationship most often fails, and it fails because nobody had the conversation before the colonies arrived.

What the grower owes. Advance notice - ideally 48 hours - of any application while colonies are on the property, with the product named, so the beekeeper can decide whether to move, confine or accept the risk. Adherence to the label's pollinator provisions, which for many products prohibit application to blooming crops when bees are foraging. Application timing that avoids foraging hours, which in practice means late evening or night application. Disclosure of tank mixes and adjuvants, because the interaction between a fungicide and an insecticide in a tank can be far more toxic than either alone, and because some adjuvants are themselves harmful in ways the label does not capture. And notice of what the neighbors are doing where the grower knows.

What the beekeeper owes. Colonies meeting the strength standard, delivered and removed on time. Accurate representation of what honey bees can and cannot do for the crop. Contact information that works and a response when called at ten at night about a spray that has to go on tomorrow. Reasonable behavior about incidents: a kill is a serious matter and sometimes an actionable one, but the beekeeper who treats every dead bee as a lawsuit will not be renting colonies for long, and the beekeeper who says nothing about a real kill has taught the grower that the term does not matter.

What both owe. A conversation before the season, not after an incident, about the grower's spray program - what goes on, when, and for what - so that the contract's restrictions are ones the grower can actually live with. A term that forbids all applications during bloom on a crop that requires a bloom-time fungicide is a term that will be broken. A term that permits that fungicide, at night, without an insecticide in the tank, is a term that will be kept.

The professional and ethical obligations extend past the contract. A beekeeper who accepts a pollination contract accepts that the colonies will be exposed to whatever is in that landscape, and cannot afterwards claim to be producing bees raised away from agricultural chemicals. A beekeeper who knowingly delivers colonies too weak to do the job has taken money for a service not rendered, and the grower usually cannot tell. A beekeeper who moves colonies out of a disease-affected operation and into a grower's field is spreading a problem into a place that has no defense against it. The traffic in colonies that pollination service requires makes each operator's hygiene partly everyone else's business.

8.17 The Stresses of Migratory Pollination

Moving colonies for pollination imposes costs that are real, measurable, and smaller than the folklore suggests, with one important qualification.

The direct stresses of transport are disturbance, confinement, heat and the mechanical agitation of a truck. Colonies are netted or confined, loaded at night, and hauled; during transit they cannot ventilate normally, cannot forage or collect water, and generate heat with no way to lose it if the load stops. Overheating on a stopped truck is the classic acute disaster. The cluster is disrupted, brood may be chilled or overheated, and queens are sometimes lost.

The measured chronic effects are modest. Comparative work on commercially migratory versus stationary colonies found that migratory management shortened adult worker lifespan by on the order of a day - about five percent of an adult worker's life - and raised markers of oxidative damage early in the season. A day sounds trivial, but the mechanism is not: shortened nurse longevity accelerates the

transition to foraging, and precocious foragers are poorer foragers who die sooner, which is the beginning of a demographic feedback loop that can unravel a colony.

The qualification is the one that ties this section back to the first half of the chapter. In the same work, food scarcity had a larger effect on oxidative stress than migration did. Migratory colonies placed in landscapes with abundant mid-season crop forage accumulated more pollen than stationary colonies sitting through a midsummer dearth, and were in some respects better off. Migration is not intrinsically the problem; migration into a nutritional desert is. A colony hauled to a monoculture, held there through and past bloom with no diverse pollen, then hauled to the next one, is being starved of dietary diversity at the same time as it is being physically stressed, and the two compound.

The other migratory costs are less about physiology. Moving colonies mixes bees and equipment across enormous distances, which is how *Varroa* strains, viruses, small hive beetle and resistant mite genotypes have been distributed nationally at a speed no natural process would achieve. Colonies converging on a single large pollination event are effectively in one enormous apiary for several weeks, sharing drifting bees and robbing opportunities. And the schedule itself compresses management: mite treatment windows, feeding windows and queen replacement all have to fit around the haul dates, and the treatment that gets skipped because the truck leaves on Tuesday is the one that would have mattered.

Mitigation is mostly nutritional and mostly obvious once stated. Move at night and in cool weather. Ventilate, and do not let a loaded truck sit. Feed - both carbohydrate and protein - on arrival and on departure, because a colony coming off a crop has spent itself. Provide water at the site. Site colonies where something other than the crop is flowering if you possibly can. Build the mite management program around the haul schedule rather than hoping to fit it in. And verify after treatment, which in the current resistance environment is the only way to know a treatment worked.

8.18 Numbers to Know Cold

Figure	Value	Why it is that value
Essential amino acids for honey bees	10	Arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine; established by de Groot in the early 1950s. Protein utilization is capped by whichever is scarcest relative to requirement
Largest single amino acid requirement	Leucine, about 16 percent of essential amino acid total	Sets the ceiling on how much of a diet's protein can actually be used
First-limiting amino acid in a substitute	Depends on the feedstuff; compare against de Groot's proportions	Protein use is capped by whichever amino acid is scarcest relative to requirement, so check each ingredient and the blend

Figure	Value	Why it is that value
Sterols bees can synthesize	None	Bees cannot make sterols from acetate; every molecule comes from pollen. This is why long-term substitute feeding fails
Dominant honey bee sterol	24-methylenecholesterol, roughly 60 to 70 percent of pupal sterol	Makes it the benchmark for judging a diet's sterol adequacy; about 0.5 percent of diet dry weight is a working target
Crude protein target in a supplemental diet	23 to 30 percent, with 20 percent a floor for brood rearing	Below this, brood rearing is protein-limited; above it, the surplus nitrogen is deaminated and wasted
Crude lipid target in a supplemental diet	5 to 8 percent	Foraging preference tracks the protein-to-lipid ratio, not protein alone
Crude protein range of natural pollens	Roughly 2 to 60 percent, most useful sources 15 to 30 percent	The spread is why diversity matters and why a single source can be inadequate
Pollen needed to rear one worker	About 125 to 190 mg, or 25 to 38 mg of usable protein	Multiply by daily brood production to get the colony's daily protein bill
Pollen consumed by one nurse bee	About 65 mg across the nursing period	Nurses, not larvae, are the main direct consumers; larvae eat glandular secretion
Colony annual pollen collection	Roughly 33 to 55 lb typical, published range far wider	Scales with brood rearing, not with adult population
Colony annual carbohydrate consumption	On the order of 120 to 175 lb honey equivalent	The harvest is only the surplus above this
Beebread pH	About 4.0 to 4.3, down from about 6 in fresh pollen	Lactic acid from *Lactobacillus* and added nectar and glandular secretions; preservation, not predigestion
Hypopharyngeal gland peak	Roughly days 6 to 12 of adult life	The nursing window; gland size is a direct readout of dietary protein status
Vitellogenin	Glycolipoprotein of about 180 kDa, made in the fat body	Brood food substrate, antioxidant, and juvenile hormone antagonist; the physiological definition of a winter bee
1:1 syrup	1 part sugar to 1 part water by weight, about 50 percent sugar	Nectar-like; stimulates comb building and brood rearing
2:1 syrup	2 parts sugar to 1 part water by weight, about 67 percent sugar	Honey-like; needs little curing, so it is stored fast without stimulating brood
Stores added per gallon of 2:1 syrup	About 7-9 lb	Use it to calculate how many gallons a light colony actually needs

Figure	Value	Why it is that value
Winter stores target, southeastern US	60+ lb of stored honey (about 100 lb total hive weight); feed if reserves fall toward 40 lb	Against 80 to 90 lb in the north; shorter winter, but early brood rearing raises late-winter consumption
Liquid feeding cutoff	Roughly 50 to 57 degrees F daytime	Below it the cluster cannot reach the feeder and cannot evaporate syrup to storage moisture; switch to solids
Moisture content of cured stores	About 17 to 18 percent	The evaporation the colony must accomplish is why cold-weather syrup feeding fails
HMF concern threshold in feed	About 30 ppm, with a tighter figure near 15 mg/kg for months-long winter exposure	Toxicity is time-reinforced, so a winter bee's six-month exposure is the limiting case
HMF formation conditions	Roughly 250 days at 86 degrees F, 10 days at 122 degrees F, 10 hours at 158 degrees F	Why syrup is stored cool and used promptly, and never boiled or acid-inverted
Nectar concentration for peak energy intake rate	Roughly 50 to 65 percent sugar	Intake rate is concentration times volumetric uptake; viscosity makes the second term fall steeply, so the product peaks in the middle
Typical nectar of bee-pollinated flowers	About 35 percent sugar, against 20 to 25 percent for hummingbird and butterfly flowers	Plants are matched to their pollinator's fluid mechanics
Bumble bee sonication frequency	About 400 Hz, against a honey bee wingbeat of 220 to 250 Hz	Poricidal anthers release pollen to vibration; honey bees do not perform the behavior
Almond colony strength standard	8-frame average, 6-frame minimum, 2 colonies per acre	The best-documented contractual standard in North America
Grading sample	About 10 percent of delivered colonies, ideally by an independent assessor	A census is impractical; a sample plus a stated method is enforceable
Grading conditions	Warm enough that bees are not clustered, commonly above about 60 degrees F, but before substantial flight	Cold undergrades by clustering; midday undergrades by emptying the box of foragers

Figure	Value	Why it is that value
Delivery timing	Roughly 5 to 25 percent bloom	Late enough that the crop dominates the landscape, early enough not to miss a short bloom
Blueberry stocking rate	3 to 5 colonies per acre, literature average near 4	Poricidal anthers mean low per-visit efficiency, compensated by numbers
Average 2025 US pollination price, almonds	209 dollars per colony	Against 54 to 87 for apples, 20 to 86 for blueberries, 71 to 114 for watermelons; about 1.63 million colonies used for almonds alone (all crops in the western regions: about 1.87 million)
Migratory effect on worker lifespan	About 1 day shorter, roughly 5 percent of adult life	Small in itself, but shortened nurse life accelerates precocious foraging
Wild insect versus honey bee per-visit effect	Wild insect visits raised fruit set about twice as much across 41 crop systems	Honey bee visits raised pollen deposition about 74 percent more strongly; the deficit is transfer quality, chiefly cross-pollination

8.19 Common Misconceptions

Misconception: If the colony has plenty of honey it is fed, and syrup will cover any gap. **Correction:** Honey and syrup are carbohydrate only. Protein, lipids, sterols, vitamins and minerals come exclusively from pollen. A colony with eighty pounds of honey and no beebread will shut brood rearing down, and feeding syrup will not restart it. Every nutritional assessment is two assessments.

Misconception: A pollen substitute with 35 percent crude protein is better than one with 25 percent. **Correction:** Crude protein is a nitrogen determination and says nothing about amino acid balance. Utilization is capped by the first limiting amino acid, so a 35 percent product short in isoleucine can deliver less usable protein than a 25 percent product with a balanced profile. Add sterol content, lipid content, palatability, actual consumption and digestibility before judging, and settle it with a feeding trial measuring brood produced per unit consumed.

Misconception: Pollen diversity matters because bees get bored of one pollen and stop collecting it. **Correction:** Bees will work a single abundant source hard for as long as it yields. Diversity matters because pollens differ in protein, amino acid balance, lipid and sterol content, so a mixed diet is far more likely to meet the full requirement. Bees on a diverse pollen blend showed higher glucose oxidase activity, an immune measure, than bees on single-source pollens, and under pathogen challenge a diverse blend survived as well as the best single pollen and better than poorer ones - and the colony gives no behavioral signal that it is heading into a deficiency.

Misconception: Beebread is superior to fresh pollen because the bees ferment and predigest it. **Correction:** The dominant process is preservation, not predigestion. Lactic acid from added nectar, glandular secretions and *Lactobacillus* activity drops the pH to about 4.0 to 4.3, which stops moulds and spoilage organisms. Bacterial abundance spikes in the first couple of days and then falls as acidity rises -

the opposite of what progressive microbial digestion would look like. Nurses prefer fresher stored pollen, and stored pollen loses value with time.

Misconception: Bees prefer concentrated nectar, so the more concentrated a solution is, the faster they gain energy from it. **Correction:** Energy intake rate is concentration multiplied by volumetric uptake rate, and uptake falls steeply as viscosity rises. The product therefore peaks at an intermediate concentration, in the region of 50 to 65 percent for honey bees, and declines above it. This is why bees abandon flowers whose nectar has thickened in hot dry weather and why very heavy syrup is taken more slowly than expected.

Misconception: Adding a little vinegar or cream of tartar to syrup inverts the sugar and helps the bees. **Correction:** Acid inversion under heat is exactly the reaction that produces hydroxymethylfurfural, which is toxic to bees at elevated concentration and whose toxicity is time-reinforced, so winter feeding is the dangerous case. Bees invert sucrose perfectly well with their own invertase. Dissolve sugar in hot but not boiling water, use no acid, store the syrup cool, and use it promptly.

Misconception: You can keep feeding syrup right through into cold weather as long as the bees are still alive. **Correction:** Below roughly 50 to 57 degrees F in the daytime, liquid feeding fails for two reasons. The cluster will not break to reach a feeder a few inches away, so the colony can starve beside full syrup. And the colony cannot ventilate hard enough to evaporate syrup down to storage moisture, so uncured syrup ferments in the combs and adds water vapor to a nest where condensation is already the main winter killer. Switch to fondant, sugar cakes or dry sugar placed directly over the cluster.

Misconception: The best sign of protein shortage is that the colony has stopped making surplus honey, or has thrown out its drones. **Correction:** The best single indicator is little or no stored beebread in and around the brood area, with brood rearing contracted despite warm weather and a laying queen present. Low surplus has a dozen causes. Drone eviction tracks stress of any kind and the ordinary autumn schedule. Bearding is thermoregulation. Look at the combs.

Misconception: A brood nest with little brood in it needs feeding. **Correction:** Only if the cells are empty. A pollen-bound brood nest, with combs packed solid with beebread and no laying space, produces the same contracted brood area and calls for the opposite intervention - removing packed frames and providing drawn comb the queen can use. Feeding a pollen-bound colony makes it worse. Distinguish the two before acting.

Misconception: Open feeding is efficient and harmless; the bees sort it out among themselves. **Correction:** They sort it out in proportion to foraging force, so the strong colonies you were not worried about take most of it and the weak ones get least. It mixes bees from many colonies and apiaries at one point, which moves foulbrood spores, nosema, viruses and beetles between colonies that would otherwise never meet. And it teaches the whole neighborhood that open sugar exists, which sets off robbing that does not stop when the barrel empties. It also draws bees from neighbors' apiaries. It is not prohibited by federal law and it does not impair natural foraging - those are distractors - but the three practical objections are sufficient.

Misconception: Feeding a jar of old crystallized supermarket honey is a thrifty way to help a small colony. **Correction:** Retail honey may originate anywhere, and *Paenibacillus larvae* spores survive in honey for decades. Feeding honey of unknown origin is a recognized route for introducing American foulbrood into a clean apiary. Feed honey only from your own colonies whose health status you have verified, and never from a jar you bought.

Misconception: A little syrup while the supers are on does no harm; it is all sugar anyway. **Correction:** Honey is defined as the product bees make from nectar or honeydew. Syrup stored in a harvest super and sold as honey is adulterated and misbranded. Remove supers intended for sale before feeding. If an emergency compels feeding during a flow, mark those supers and keep the resulting stores out of the crop.

Misconception: Planting a pollinator garden will feed my bees. **Correction:** A colony forages over several square miles, routinely exploiting dozens of square miles over a season. A garden or a small planting is a rounding error against that. Site selection - choosing a location whose surrounding landscape offers a succession of diverse blooms - matters far more than planting, and nothing a beekeeper does changes how much nectar a plant secretes, which is set by species, genotype, weather and soil moisture. Plant for native bees, by all means. Do not tell a new beekeeper it will feed an apiary.

Misconception: Honey bees are poor pollinators of blueberry because they cannot see the flowers or because the nectar is mildly toxic. **Correction:** Neither is true. The anthers are poricidal and release pollen efficiently only to sonication - a high-frequency vibration bumble bees and many native bees perform and honey bees do not. Honey bees visit for nectar and effect some pollination; growers compensate with high stocking density and, where it pays, managed bumble bees and habitat for native species.

Misconception: Honey bees dominate commercial pollination because they are the most efficient pollinators. **Correction:** They are frequently mediocre per visit - a large multi-crop analysis found wild insect visitation raised fruit set about twice as much per unit increase, and honey bee visitation raised it significantly in only about 14 percent of crop systems. What honey bees have is the other term in the product: they can be delivered by the tens of thousands per acre, on a date the grower chooses, to fields with no resident pollinator population. Overall effectiveness is per-visit efficiency times visits delivered, and in monoculture the second term dominates.

Misconception: Get colonies onto the crop early so they are established and ready when it opens. **Correction:** That is precisely the failure mode. A colony placed early recruits onto whatever is already flowering nearby and, because foragers are faithful to a rewarding source, keeps working it when the crop opens. Delivering at roughly 5 to 25 percent bloom means the target crop is the most abundant resource at the moment the colony orients. The exceptions are real - a crop with no competitor in range, or access roads that will be impassable later - but they are exceptions, not the rule.

Misconception: Grade the colonies on a nice warm afternoon so the bees are active and you can see them. **Correction:** On a warm afternoon a large fraction of the population is in the field, so the box undergrades the colony. In cold weather the cluster is tight and spans fewer frames, which also undergrades it. Grade when the bees are expanded but not yet flying - early morning, or a cool overcast

day above about 60 degrees F - and tip the boxes to count the frame undersides rather than looking down from above.

Misconception: Apiary carrying capacity is a regulatory limit, or a property of the hive stand. **Correction:** It is the number of colonies a location can support without forage competition depressing per-colony productivity and condition, set by forage abundance, diversity and timing within flight range. It moves between years with rainfall and land management, and other beekeepers' colonies within range count against it whether or not you know they are there. Estimate it empirically with weight records, a three-mile forage survey, and incremental scaling while watching per-colony rather than yard totals.

8.20 Self-Check Questions

- A colony in mid-August has forty pounds of capped honey, a laying queen, warm weather, and a brood nest that has shrunk to two frames. The combs flanking the brood are empty. State the most likely diagnosis, the one alternative you must rule out first, and how you would distinguish them in thirty seconds with the hive open.
- Explain, from physiology, why a pollen substitute can support good brood rearing for five weeks and then produce a steady decline even though nothing about the formulation has changed.
- A supplier offers two patties, one at 32 percent crude protein and one at 24 percent. Give four questions you would ask before choosing, and say what field measurement would settle the matter.
- Derive, rather than assert, why the net rate of energy gain from nectar peaks at an intermediate concentration. Then explain two field observations that follow from it.
- You are called on 12 January to a colony that is very light. The forecast high is 44 degrees F for the next week. State what you will feed, where you will place it, and give the two distinct physiological reasons syrup would fail.
- Explain the role of vitellogenin in winter survival and state precisely which management window determines whether a colony will have it.
- A grower asks why he should pay for four colonies per acre on rabbiteye blueberry when his neighbor pays for two on apples. Answer him in a way that is accurate about honey bee pollination of blueberry without talking yourself out of the contract.
- Give the temperature and time-of-day conditions under which you would want your colonies graded for a pollination contract, and explain both of the errors you are avoiding and why they run in the same direction.
- Distinguish per-visit pollinator efficiency from overall pollination effectiveness. Then explain why the distinction fails to save honey bees on crops requiring sonication.
- A beekeeper stores forty gallons of high-fructose corn syrup on a trailer through July and feeds it in October for winter stores. Identify the specific risk, give the chemistry, give a threshold figure, and explain why the winter timing makes it worse than the same syrup fed in June.

- Name the five contract terms whose absence causes the most disputes, and for each say what specifically goes wrong when it is missing.
- Explain why open feeding distributes syrup in exactly the wrong direction, and give two further objections that have nothing to do with distribution.
- A new beekeeper tells you she is planting a quarter acre of wildflowers so her two colonies will have enough forage. Give her an honest answer that does not discourage the planting.
- Summarize what is known about the effect of migratory pollination on colonies, and state the confounding factor that changes the interpretation.

8.21 Self-Check Answers

- The most likely diagnosis is protein shortage: the empty cells around the brood mean beebread has been consumed and not replaced, and with a laying queen, warm weather and adequate carbohydrate, protein is what is limiting. The alternative to rule out first is a pollen-bound brood nest, which produces the same contracted brood area for the opposite reason. The thirty-second discrimination is to look at the cells: if the combs flanking and within the brood area are empty and available, it is a dearth and wants feeding; if they are packed solid with beebread so the queen has nowhere to lay, it wants laying space and feeding would make it worse. The question also implies checking that the queen is present and laying, since a failing queen produces a third version of the same symptom.
- Residual sterol reserves carry the colony through the early period. Bees cannot synthesize sterols from acetate, so every molecule in membranes and moulting hormone precursors must come from the diet; 24-methylenecholesterol alone makes up something like 60 to 70 percent of pupal sterol. A substitute without an adequate sterol source draws down the reserves in the adult bees and in residual beebread, and those last several weeks. Once they are exhausted, brood rearing declines regardless of how good the protein figure looks, because the deficit is not protein. The same logic explains why the decline is gradual rather than abrupt and why it is so often misattributed to queen failure or disease.
- Ask: what is the amino acid profile, and which amino acid is first limiting relative to the de Groot proportions? What is the sterol source, and how much 24-methylenecholesterol or equivalent does it supply? What is the lipid content, and therefore the protein-to-lipid ratio? What is documented consumption under field conditions, since an uneaten patty is worth nothing? A fifth worth adding is digestibility and freedom from antinutritional factors. The field measurement that settles it is a feeding trial against a control measuring brood area produced per unit of substitute consumed, run long enough - eight weeks or more - that any sterol deficiency has time to express itself. Anything shorter measures palatability and residual reserves.
- Energy intake rate is the product of two terms: the sugar concentration of the solution, and the volumetric rate at which the bee can get it into her crop. The first rises linearly with concentration. The second falls as viscosity rises, and viscosity rises far faster than concentration does - approximately exponentially over the relevant range. A rising linear term multiplied by a steeply falling one produces a curve with an interior maximum, in the region of 50 to 65 percent for honey bees. Two consequences: bees abandon flowers whose nectar has concentrated by evaporation in hot dry weather even though it is now richer in sugar; and very heavy syrup is

taken more slowly than beekeepers expect, so 2:1 syrup is preferred in autumn for its low curing requirement rather than for speed of uptake.

- Feed a solid - fondant for preference in a colony of uncertain strength, otherwise a sugar cake or dry sugar on newspaper - placed directly on the top bars immediately above the cluster, under a shim or empty super. If a frame of capped honey from a colony of verified health is available, that is better still, placed adjacent to the cluster. Syrup fails for two separate reasons. Access: at 44 degrees F the cluster will not break to travel to a feeder, so the colony can starve within inches of full syrup. Ripening: the colony cannot ventilate hard enough to evaporate syrup down to about 17 or 18 percent moisture, so it ferments in the combs and adds water vapor to a nest where condensation dripping on the cluster is already the principal winter hazard.

- Vitellogenin is a glycolipoprotein of about 180 kilodaltons made in the fat body. It is the protein reserve drawn on for brood food synthesis, an antioxidant that limits accumulated oxidative damage, and a juvenile hormone antagonist that suppresses the transition to foraging - so a bee with a high titre stays in the nest and stays young. A winter bee is physiologically defined by a high vitellogenin titre and a large fat body, and she is produced by being reared in autumn on adequate pollen with little brood to feed. The determining management window is therefore the autumn pollen supply, which in the southeastern US means the goldenrod and aster bloom. A poor autumn bloom produces bees with summer physiology, and the colony dwindles in late winter without ever looking obviously diseased.

- Blueberry anthers are poricidal - they hold pollen in a tube with a pore, and release it efficiently only to sonication, a high-frequency vibration that bumble bees and several native bees perform and honey bees do not. Honey bees visit blueberry for nectar and do effect pollination, but their per-visit efficiency is low, so the crop needs many more visits to reach the same pollen transfer. That is what the higher stocking rate buys: number of visits compensating for efficiency per visit. Apple is a crop honey bees work well, so fewer colonies deliver the same result. Say also what it buys the grower to manage habitat for native bees and, where the economics work, managed bumble bees alongside the honey bees - which is an honest recommendation and the one that tends to get a beekeeper invited back.

- Grade when the bees are expanded across the frames but the flying force has not yet left: early morning before substantial flight, or on a cool overcast day, with the temperature warm enough that the colony is not balled - commonly given as above about 60 degrees F. Both errors run in the same direction, which is why they matter. In cold, the cluster contracts and spans fewer frames than the population would otherwise occupy, so the colony undergrades. At midday in warm weather, a large fraction of the population is out foraging and not in the box, so the colony undergrades again. Method matters too: tip the boxes off the bottom board and off each other and count the frame undersides, because looking down into an open box from above misses most of the bees.

- Per-visit efficiency is pollen deposited on a receptive stigma, or fruit set achieved, per individual flower visit - a property of the insect’s behavior and morphology relative to that flower. Overall effectiveness at crop level is that figure multiplied by the number of visits delivered, which depends on forager numbers, foraging duration, weather tolerance and manageability. Honey bees are often mediocre on the first and unmatched on the second, and in large-scale monoculture the second dominates. The distinction fails on sonication crops because there the per-visit efficiency for the specific mechanism that releases the pollen is effectively zero: honey

bees do not sonicate at all, so multiplying by a large number of visits multiplies an incidental contribution rather than the main one. Numerical advantage compensates partially, not fully, which is why integrated approaches are appropriate.

- The risk is hydroxymethylfurfural. HMF forms when sugar solutions are held warm, particularly under acid conditions, by degradation of hexoses; fructose is more prone than glucose, so high-fructose corn syrup is the worst case, and a trailer in July is well into the accumulation regime - roughly ten days at 122 degrees F is enough, against 250 days at 86 degrees F. A commonly used concern threshold is 30 parts per million in bee feed. Winter timing makes it worse because HMF toxicity is time-reinforced: a summer bee is exposed for three weeks, a winter bee for six months, and risk assessment adjusting for a 180-day exposure drops the acceptable level to around 15 milligrams per kilogram. The syrup that would be harmless in June may not be harmless as a winter store.

- Colony strength standard with the method, timing and conditions of assessment - without it, the grower and beekeeper disagree about what was delivered and have no agreed way to find out. Delivery and removal dates keyed to bloom stage - without them, colonies arrive early and fix on competing forage, or leave before the last variety has finished, or sit in a post-bloom field about to be sprayed. Number of colonies and stocking rate - without both, the grower buys a count and expects a rate. Pesticide undertakings including advance notification and tank mix disclosure - the term most often omitted and most often regretted, because without it the beekeeper's first knowledge of an application is a pile of dead bees. Price, payment terms and the adjustment for colonies failing the standard - a standard with no stated consequence is not a standard, and a beekeeper with no payment terms is an unsecured creditor.

- Syrup in a communal container is collected in proportion to each colony's foraging force, so the strong colonies that did not need it take most of it and the weak colonies that did take least - the opposite of the intended distribution. Two further objections: it concentrates bees from many colonies and many apiaries at a single point, which is an efficient route for foulbrood spores, nosema, viruses and small hive beetles to move between colonies with no other contact; and it teaches every colony in flight range that exposed sugar exists, initiating robbing behavior that does not stop when the container empties and that frequently ends in a dead colony. It also draws bees from neighbors' apiaries, which compounds the disease objection.

- Tell her the planting is worth doing and then tell her why it will not do what she thinks. A colony forages over several square miles and will exploit dozens of square miles over a season; a quarter acre is a rounding error against that, and what her colonies eat will overwhelmingly come from land she does not control. What will actually determine how well her bees are fed is the forage calendar of the landscape within about three miles of the hives - whether it offers a succession of diverse blooms or one big flow and a long gap - and whether she is prepared to feed through the gaps. The planting will genuinely help native bees, which forage over hundreds of meters rather than miles, and it will help most if she chooses plants that bloom in the midsummer dearth rather than in spring when everything is already flowering.

- Migratory management imposes real but modest measured costs: shortened adult worker lifespan by on the order of a day, roughly five percent of adult life, and elevated markers of oxidative damage early in the season. The mechanism by which a small number matters is demographic - shortened nurse longevity accelerates the transition to foraging, and precocious foragers forage poorly and die sooner. The confounding factor is nutrition. In the same work,

food scarcity had a larger effect on oxidative stress than migration did, and migratory colonies placed where mid-season crop forage was abundant accumulated more pollen than stationary colonies sitting through a midsummer dearth. Migration into a nutritional desert is the problem, not migration as such. Separate migratory effects also include the national distribution of pests and pathogens, and the compression of treatment and feeding windows around haul dates.

8.22 Further Reading

- Graham, J. M. (ed.), *The Hive and the Honey Bee*, Dadant & Sons, 2015 edition. The nutrition and pollination chapters are the standard reference; read them alongside this chapter.
- Sammataro, D. & Avitabile, A., *The Beekeeper's Handbook*, 5th edition, Cornell University Press, 2021. Practical feeding methods, feeder types and seasonal management.
- Caron, D. M. & Connor, L. J., *Honey Bee Biology and Beekeeping*, revised edition, Wicwas Press. Good on nutrition fundamentals at the level this chapter assumes.
- Somerville, D., *Fat Bees Skinny Bees: A manual on honey bee nutrition for beekeepers*, Rural Industries Research and Development Corporation, Publication 05/054, 2005. Freely available and still the best single practical treatment of colony nutrition; written for Australian conditions but the physiology travels.
- Honey Bee Health Coalition, *Honey Bee Nutrition: A Review and Guide to Supplemental Feeding*. Current, free, and the most useful single document on diet formulation, feeding decisions and feeder selection.
- de Groot, A. P., "Protein and amino acid requirements of the honeybee (*Apis mellifica* L.)", *Physiologia Comparata et Oecologia*, volume 3, 1953. The foundational work on the ten essential amino acids and their proportions.
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Chapter 9. Regional Bee Botany & Honey Plants

Covers exam questions Q159-Q175.

9.1 Orientation

Bee botany is where a beekeeper's calendar comes from. Everything in the management year - when to build up, when to super, when swarm risk peaks, when to split, when to feed, when a mite treatment can go on without honey supers in the way - is downstream of what is blooming, when, and how much nectar it is giving. A candidate who has memorized a plant list has learned the least useful part of the subject. The examinable part is the reasoning that connects a plant's biology to a management decision.

Three ideas organize this chapter.

The first is that in the southeastern US the calendar runs early, and the main opportunity arrives before a beekeeper working from a northern textbook is ready for it. Colonies begin expanding in late winter on maple and willow pollen; the principal flow opens in mid spring and is frequently over by early summer. A beekeeper who supers in May because that is when the book says to super has already missed the crop. Everything about regional management - early build-up, early swarm control, early supering, a long summer dearth to manage afterward - follows from that one displacement of the calendar.

The second is that a plant list is a much weaker predictor than beekeepers want it to be. Nectar secretion is a physiological process under the control of genotype, plant age and vigor, soil moisture, temperature, humidity and stress, and it varies enough between years that the same stand of the same species can give a surplus one season and nothing the next. The consequence for the exam and for the craft is the same: the authority on a location is the beekeeper's own weight records and bloom notes, not a published list, and the notes must be kept against weather rather than against calendar dates.

The third is that this region is not one place. Its honey crops are determined by physiography. Tupelo is a river-swamp crop of a few river systems of the coastal plain, from South Carolina to northwest Florida, and cannot be produced elsewhere at any level of skill. Sourwood is a crop of the southern Appalachian mountains and foothills, and largely of the higher ground within them. Gallberry belongs to the wet pine flatwoods of the coastal plain. Tulip poplar and *Rubus* are the broad common denominator across the piedmont and much of the rest. When an item names a crop, it is usually testing whether you know the landform it belongs to, because that is what determines whether the crop is available to a given beekeeper at all.

9.2 How a Nectary Works, and What Governs Secretion

A nectary is a secretory tissue, not a reservoir. Nectar is derived from phloem sap: sugars arrive at the nectary parenchyma through the phloem, are processed there, and are released either through modified stomata that do not close or by rupture of the cuticle over the secretory cells. The plant is spending photosynthate to buy pollination, and like any other expenditure it is regulated according to the plant's condition.

What is released is not phloem sap. Nectary tissue commonly carries a cell-wall invertase that hydrolyzes sucrose into glucose and fructose, and the degree of hydrolysis differs by species. This is the origin of the distinction between sucrose-dominant nectars (typical of many long-tubed flowers, such as the mints and the buttercup family) and hexose-dominant nectars (typical of many open, short-tubed flowers, including the mustard family, Brassicaceae, and many Asteraceae). That hexose-rich, glucose-heavy nectar is why canola honey can set in the comb, and it is the first link in the chain that ends with one honey granulating in the jar in six weeks and another staying liquid for three years. The bee adds her own invertase from the hypopharyngeal glands during the trip home and during ripening, so nearly all of the sucrose ends up hydrolyzed in the finished honey; but the glucose-to-fructose balance the plant delivered is essentially preserved, because invertase produces the two hexoses in equal measure and cannot convert one into the other.

Nectar also carries amino acids, organic acids, minerals, phenolics, terpenes and other secondary compounds in small quantities. These are trivial as nutrition and decisive as sensory chemistry: they are most of what makes sourwood taste like sourwood, they carry over into the honey, and the mineral fraction is a major driver of color.

9.2.1 Concentration and why bees are selective

Fresh nectar ranges from about 5 percent sugar to well over 60 percent. Bees strongly prefer the middle: field work consistently finds foragers working sources in the 30 to 50 percent range in preference to thinner ones, and essentially ignoring nectar below roughly 10 to 15 percent sugar unless nothing else is on offer. The reason is energetic. A forager must carry the water home and the colony must evaporate it. To make a pound of honey at about 17 percent moisture from nectar at 40 percent sugar takes roughly two pounds of nectar; from nectar at 20 percent sugar it takes something over four pounds, with all the flight time, the handling, the fanning and the ventilation that implies. Thin nectar can be a net loss to the colony in hot, humid weather, when evaporation is slow and the bees' cost of processing rises. Very concentrated nectar carries the opposite problem - above roughly 60 to 65 percent it is too viscous to draw up efficiently, and bees dilute it with water or work it slowly.

Concentration is also a weather variable rather than a plant constant. The same flower in the same hour gives thinner nectar in high humidity and more concentrated nectar in dry air, because standing nectar equilibrates with the surrounding vapor pressure after secretion. This is why a flow can appear to "turn on" after a dry spell without any change in the rate of secretion at all.

9.2.2 What makes secretion vary

Master-level items on this subject are nearly always testing the same distinction: secretion is not a species constant. The variables that matter:

- **Species and genotype.** Different species differ by orders of magnitude, and within a species cultivars differ enormously. Ornamental and heavily bred cultivars are frequently poor nectar producers relative to wild types, and double-flowered cultivars are often nectarless, having converted the nectar-bearing parts into petals.

- **Plant age and vigor.** A tulip poplar usually does not flower until it is roughly 15 to 20 years old, and a mature dominant tree in full sun with a large crown gives what a suppressed sapling in the understory cannot. Stand age and canopy position matter as much as species.
- **Soil moisture and rainfall.** This is the single largest year-to-year driver in this region. Drought shuts down secretion; heavy rain during bloom washes nectar out of open flowers and grounds the bees. The ideal pattern is adequate soil moisture built up before the bloom and dry, warm weather during it.
- **Temperature.** Every species has a temperature window for secretion. Cold nights during a bloom depress the following day's yield, and unusually hot weather can shorten the bloom by pushing the whole stand through anthesis faster.
- **Humidity, wind and aspect.** Humidity sets nectar concentration; hot dry wind can dry standing nectar to the point where bees cannot recover it; a south-facing slope opens days ahead of a north-facing one.
- **Plant stress.** Insect damage, disease, competition and nutrient limitation all reduce secretion, because nectar is discretionary spending.
- **Time of day and flower age.** Many species secrete on a daily rhythm - some species peak in the afternoon, others in the morning - and most flowers give most of their nectar in the first day or two of anthesis.

A practical corollary the exam likes: **placing more colonies does not increase the resource.** Nectar removal does not stimulate the plant to produce more in any way that matters at colony scale. The supply within flight range in a given season is roughly fixed, so adding colonies divides it. That is the entire basis of apiary carrying capacity, and it is why the honest answer to "how many hives can I put here" is a question about the surrounding two to three miles rather than about the acre the pallets sit on.

9.3 Extrafloral Nectaries, and Why Cotton Matters

An **extrafloral nectary** is a nectar-secreting structure located outside the flower - on leaves, leaf midribs, petioles, stipules, bracts or the flower's outer surface - and not involved in pollination. Its usual ecological role is defensive: it recruits ants, wasps and predatory arthropods, which patrol the plant for the sugar and incidentally attack the herbivores they meet. The plant is paying a standing army in syrup. Biochemically these nectaries are close kin to floral ones; the secretory machinery is largely conserved, and the difference is location and function, not mechanism.

Cotton is the example that matters in this region, and it bears both kinds. Its floral nectaries sit inside the flower; its extrafloral nectaries occur on the underside of the leaf along the midrib and on the bracts around the bud, both outside and inside the involucre. The leaf nectaries secrete modestly throughout the season. The bract nectaries secrete heavily from squaring through boll development, peaking around flowering and continuing after the flower has fallen, and they secrete a sugar solution bees will work readily.

Two practical consequences follow, and the second is the more important.

First, cotton can contribute to a honey crop. Cotton honey is light, mild and typically granulates fairly readily - a relatively high-glucose honey. In some years and some districts it gives a real surplus; in others it is a maintenance flow that keeps colonies fed through part of the summer.

Second, and this is the point worth carrying into a conversation with a grower: **a crop that is not blooming can still be full of bees.** An applicator reasoning that "there are no flowers, therefore there are no pollinators, therefore standard pollinator precautions do not apply" is making a defensible-sounding inference that happens to be wrong on cotton. Because the bract nectaries keep secreting from squaring through boll development, and because much insecticide use on cotton targets pests that are scouted and sprayed during the season regardless of bloom stage, the exposure window is wide. The specific, useful thing a master beekeeper can say to a grower or an applicator is that cotton feeds bees from its leaves and bracts, not only from its flowers, and that spray timing should be set accordingly - early morning or evening applications, and notification of nearby beekeepers.

Cotton also illustrates a separate point about pollen. Cotton pollen grains are large, spiny and coated in a sticky pollenkitt; honey bees handle them poorly and pack them into corbiculae inefficiently. So cotton can be a significant nectar source and an insignificant pollen source at the same time. Nectar value and pollen value are separate questions about any plant, and the exam tests that separation repeatedly.

Other plants bearing extrafloral nectaries that a beekeeper in the region will encounter include several *Vicia* species (vetches), some *Prunus* (cherries and plums, with nectaries on the petiole), *Passiflora*, elderberry, and many legumes. The generalization is what matters: whenever a non-flowering crop or plant is being treated near an apiary, the question "does it have extrafloral nectaries" is worth asking.

9.4 Pollen Value Versus Nectar Value: Corn and Pine

Two dominant plants in regional landscapes are useful precisely because they force the pollen/nectar distinction.

Corn is wind-pollinated. It produces no nectar at all - there is nothing for a bee to drink - yet bees work it heavily for pollen, sometimes to the near-exclusion of other sources during tasseling, because it sheds enormous quantities of an easily gathered pollen at a season when alternatives may be thin. Corn pollen is mediocre protein, below the crude protein levels of good natural pollens and deficient in some essential amino acids, so heavy reliance on it is a nutritional problem as well as an exposure problem.

The exposure problem is the examinable one. Because corn is not considered a bee-attractive crop in the ordinary sense - no nectar, no pollinator contract, no bloom in the colloquial sense - it is frequently treated without pollinator precautions while bees are working it hard. Corn is also the crop most associated with neonicotinoid seed treatment, which puts insecticide into the plant systemically and, more acutely, into the abraded talc or graphite dust exhausted by pneumatic planters at planting time. Krupke and colleagues documented neonicotinoid residues in that planter dust, in soil, in dandelions and other non-target vegetation near planted fields, and in dead and dying bees at affected apiaries. A beekeeper near substantial row-crop acreage should know the local planting window and the local tasseling window and should have had a conversation with the grower about both.

Pine is the opposite kind of trap. Pine-dominated land is the default land cover across much of the coastal plain and a great deal of the piedmont. Pines are wind-pollinated, yield no nectar, and produce colossal volumes of a pollen that is low in protein, low in usable lipid and poorly digested. Bees do collect some of it - the yellow film on every horizontal surface in early spring finds its way into corbiculae - but it is closer to filler than to food, and no colony builds on pine pollen.

The correct way to evaluate a pine-dominated site, therefore, is to ignore the canopy and look at the understory and the surrounding land. Open, frequently burned pine flatwoods with a maintained shrub layer can be excellent, because that is where gallberry lives. A closed-canopy loblolly plantation at age fifteen, dark underneath and swept clean of understory, is close to a biological desert for bees. Between those extremes sit every combination of thinning, burning, herbicide release, firebreak, powerline right-of-way, stream buffer and adjoining pasture. The site's value is the sum of the bloom sequence available within flight range, and the canopy species is nearly irrelevant to it.

That flight-range arithmetic is worth having in hand. A two-mile foraging radius encloses about 12.5 square miles, roughly 8,000 acres; a three-mile radius encloses about 28 square miles, roughly 18,000 acres. Foraging is heavily weighted toward the near end of that range because flight costs energy, but the far end is available when the near end is empty. When evaluating a site, the honest unit of analysis is thousands of acres, not the field you are standing in.

9.5 The Nectar Calendar of the Region

Dates below are given as seasons rather than as calendar dates on purpose. Bloom in this region shifts by two to four weeks between the warmest coastal ground and the higher mountains, and by a week or more between years at a single site. The sequence is stable; the dates are not.

9.5.1 Late winter: the trigger, not the crop

Red maple and the willows open first, frequently while nights are still freezing. Maple in particular can be in full bloom at a time when a beekeeper is still thinking of the colony as wintering. Alder, elm, hazel and the winter weeds - henbit, purple deadnettle, chickweed - follow or overlap, then dandelion, then early fruit bloom on plum, pear and the wild cherries.

None of this is a crop. In most years none of it produces a surplus worth supering for, and some of it produces essentially no surplus at all. Its importance is that it starts the colony.

The reason early pollen matters more than early nectar is a matter of what the colony has in reserve. A wintering colony normally still holds honey, and where it does not the beekeeper can feed syrup, which the bees will take and use directly. There is no comparable protein reserve. Stored beebread is finite and by late winter often largely spent, and the bee's own protein store - the fat body and the vitellogenin titer of the winter bees - is a buffer for maintaining those bees, not a stock for rearing new ones at scale. Brood food comes from the hypopharyngeal and mandibular glands of nurse bees, and those glands are built and maintained on dietary protein. Incoming pollen is therefore the input that permits the brood nest to expand, and the expansion is self-reinforcing: more brood reared now produces more foragers in three to four weeks, which collect more pollen, which supports more brood.

Two practical consequences. First, incoming pollen loads are the signal that build-up has begun - the cheapest colony assessment available in late winter is standing at the entrance on a warm afternoon and watching what comes in. Second, a beekeeper who wants colonies at strength for a mid-spring flow must ensure protein is available in the six to eight weeks before it, from natural forage or from a substitute, because the bees that will forage the flow must be reared before it opens, and the nurses that rear them must be fed before that. A colony fed sugar syrup and no protein in late winter will build far more slowly than one with pollen coming in, and the beekeeper will blame the weather.

Useful early pollen sources to know for the region: red maple, willow, alder, elm, hazel, henbit and purple deadnettle, dandelion, and early *Prunus* and *Pyrus* bloom. Maple and willow are the two named most often, and both give some nectar as well.

9.5.2 The main spring flow: tulip poplar and the brambles

Tulip poplar (*Liriodendron tulipifera*, a magnolia relative and not a poplar at all) is the backbone of the spring crop across the piedmont and much of the region outside the driest coastal plain. It blooms in mid spring, typically over two to three weeks, and its flowers are large, cup-shaped and generous: nectar collects in the base of the tepals in quantities a beekeeper can tip out of a picked flower. An old estimate, often repeated (it appears in the USDA Silvics manual), credits a single tree under twenty years old with about 8 lb of nectar in a season, equal to roughly 4 lb of honey; treat the figure as an order of magnitude rather than a constant, but the order of magnitude is right, and it explains why a stand of mature poplar can put fifty pounds on a colony in a fortnight.

Poplar honey is dark - reddish to purplish amber - with a strong, distinctive, slightly resinous flavor that some buyers prize and others dislike. Its darkness comes largely from a high mineral content and a heavy load of phenolic compounds, the same chemistry that makes dark honeys generally higher in antioxidant activity and stronger in flavor. It is frequently sold as a varietal and is also the standard base for a blended regional table honey.

The exam's recurring point about poplar is a management point, not a botanical one: **it comes early, and it is over quickly.** To take a crop from it, the colony must already be at foraging strength when it opens - meaning the build-up decisions were made six to eight weeks earlier - and supers must be on before the first flowers open, not after the beekeeper notices the flow. Honey left ungathered because there was nowhere to put it is the commonest avoidable loss in regional beekeeping, and it is the direct consequence of running a northern calendar in a southern spring.

Blackberry and dewberry (*Rubus* species) bloom with or just after poplar and are the most dependable spring source across the widest range of sites in the region, precisely because they are weeds of disturbance: roadsides, fencerows, field margins, powerline rights-of-way, cutover timberland, abandoned pasture. A site with no forest worth the name and no crop worth the name may still have miles of *Rubus*. The honey is light and mild, and in practice it mixes with poplar into the general spring crop unless deliberately separated.

The examinable coincidence is this: *Rubus* bloom, and the main spring flow generally, lands almost exactly on the peak of colony population and therefore on the peak of swarming. That is not accidental.

Colony population, swarming and the main flow are all driven by the same seasonal resource pulse, and the colony's reproductive strategy is to swarm when forage is abundant enough to establish a daughter colony. For the beekeeper, it means the highest-value weeks of the year are also the weeks in which a colony is most likely to halve itself and take the crop with it. Supering and swarm management are not sequential tasks in this region; they are the same inspection.

9.5.3 Late spring into early summer on the coastal plain: gallberry

Gallberry (*Ilex glabra*), also called inkberry, is a low evergreen holly of the wet pine flatwoods, pocosins and savannas of the coastal plain - typically waist to head high, spreading by rhizomes into dense thickets. It flowers in late spring into early summer, after or overlapping the tail of poplar and *Rubus*, and it has been one of the region's historically important commercial honeys: light amber, with noticeably heavy body, a mild distinctive flavor, and slow granulation, which historically made it valuable to the comb honey and chunk honey trade as well as for extraction. A related species, large gallberry (*Ilex coriacea*), occupies wetter ground and contributes as well.

Gallberry is the cleanest regional illustration of a general principle: **a honey crop is a product of land management, not only of botany.** Gallberry is a fire-adapted shrub of open pine woodland. It resprouts vigorously from rhizomes and root crowns after burning, and it flowers best in the open, sunlit understory that a frequent low-intensity fire regime maintains. Fire suppression lets the canopy close and hardwoods and shrubs shade it out; dense plantation forestry does the same; site preparation, herbicide release and conversion to agriculture or development remove it outright. Where frequent prescribed fire is practiced, the gallberry crop persists. Where it is not, it declines within a couple of decades without any change in the underlying soils or climate.

The same reasoning transfers directly: clover honey depends on grazing and pasture management, roadside and field-margin crops depend on mowing schedules and herbicide use, and any regional flow depends on what the surrounding landowners decide to do with their land. The beekeeper's leverage over a crop is often a conversation with a land manager rather than anything done in the apiary.

9.5.4 The river swamps: tupelo and the discipline it demands

Genuine tupelo honey comes from **Ogeechee tupelo**, *Nyssa ogeche*, a small tree of river swamps and floodplain edges in the coastal plain from South Carolina through Georgia to north and northwest Florida. Commercial tupelo honey comes overwhelmingly from a handful of river systems, above all the Apalachicola and Chipola in the Florida panhandle. This is the tightest geography of any crop discussed here, and no management substitutes for it. Note the species carefully: black tupelo or black gum, *Nyssa sylvatica*, is widespread across the region and is a useful bee plant, but it is not the source of commercial tupelo honey and yields a darker honey.

Nyssa ogeche blooms in early to mid spring (about late March to early May), over a window of roughly two to three weeks. The honey is very light, with a delicate, mild, faintly floral flavor, and it commands a large premium - several times the price of bulk honey.

Its commercial property, and the one an exam item will ask about, is that **it resists granulation almost indefinitely.** The mechanism is the fructose-to-glucose ratio. Glucose, not fructose, is the sugar that

crystallizes out of honey, as glucose monohydrate; fructose is far more soluble and stays in solution. Average US honey runs about 38 percent fructose and 31 percent glucose - a ratio near 1.2 - and granulates within months. Tupelo carries an unusually high fructose fraction and a low glucose fraction, so there is simply not enough glucose relative to the water present to nucleate and grow crystals at ordinary storage conditions. Because fructose has a lower glycemic index than glucose, tupelo is often marketed as a lower-glycemic honey, but published glycemic index measurements for tupelo itself are scarce, and the claim should be stated cautiously.

Producing it requires the full discipline of varietal production, under difficult conditions:

- Every super must be clear of other honey before the bloom opens. Whatever is on the hive when tupelo starts will end up in the jar, and titi, willow and black gum bloom before it while gallberry follows it - so the window is bracketed on both sides by sources that will spoil it.
- Supers must come off promptly when the bloom ends, before the following flow contaminates the crop.
- Colonies are frequently worked on platforms or by boat, because the bloom is in a floodplain and the crop is lost to a river rise at the wrong moment.
- Weather during a two-to-three-week window decides the entire year's production of the varietal.

That combination - very high value, very short window, very small geography, high weather and flood risk - is the point. Tupelo is a high-risk, high-reward specialty, and the risk is structural rather than a matter of skill.

9.5.5 The mountains and foothills: sourwood

Sourwood (*Oxydendrum arboreum*) is an understory and edge tree of the southern Appalachian mountains and foothills. It blooms in early summer, in the weeks after the main spring flow has ended - which is precisely what makes it valuable, because it occupies a slot that would otherwise be the beginning of the summer dearth. Its white, urn-shaped flowers hang in one-sided racemes, and the tree is a member of the heath family, *Ericaceae*.

Sourwood honey is light amber with a distinctive flavor usually described in terms of caramel, spice and a clean lingering finish; it is one of the two or three most valuable varietal honeys produced in the US and frequently sells for several times the price of bulk honey. It is also slow to granulate, though not as reliably liquid as tupelo.

The exam's point about sourwood is geographic. Nectar yield is strongly tied to elevation and to the mountain and foothill environment; production is poor below roughly a thousand feet and improves with elevation into the higher country. A beekeeper on the coastal plain of the region will never produce sourwood honey, regardless of skill, because the tree either is not there or does not yield there. This is the general lesson about varietals in miniature: the crop belongs to a landform.

Producing a marketable sourwood crop requires the same discipline as tupelo - clean supers on specifically for that bloom, after spring honey has been removed, so the crop is not diluted with poplar

or clover - and it is worth doing because the price differential is large. A sourwood crop diluted with spring honey is just honey.

9.5.6 Midsummer: the dearth

After the spring flow ends - and after sourwood in the mountains and gallberry on the coastal plain - much of the region goes into a genuine summer dearth. It is hot, standing forage is limited, and colonies that were at maximum population in late spring are now consuming stores rather than adding to them.

The dearth is a management period in its own right and is discussed in the seasonal chapter, but it belongs to botany in one respect: a beekeeper who has identified the dearth's start and end dates for their own location has the key to most of the year's decisions. Robbing risk rises sharply during dearth; small hive beetle pressure builds; splits made into a dearth need feeding; queens mate into a dearth less reliably; and the post-harvest mite treatment window sits within it.

Scattered sources bridge the gap in some landscapes - cotton where it is grown, sumac, chinquapin and the chestnut relatives, basswood in the mountains, clovers and lespedeza on managed ground, and in the Gulf coastal areas Chinese tallow. None of these is reliable across the whole region, which is why the dearth is defined locally.

9.5.7 Autumn: goldenrod and aster

Goldenrod (*Solidago* species) and the fall asters, with Spanish needles and other composites, produce the region's last significant bloom. Both are heavy pollen producers as well as nectar sources, and that dual role is what makes them important.

The examinable framing is that the fall flow is **nutrition, not a crop.** The bees reared on that pollen are the physiologically distinct long-lived winter bees - high vitellogenin titer, well-developed fat body, reared in autumn on abundant protein. Their quality determines whether the colony goes into winter with an adequate population and comes out of it able to build. Harvesting the fall crop takes that winter feed away and replaces it, if the beekeeper is diligent, with sugar syrup that supplies energy and no protein at all. In most of this region the fall crop stays on the colony.

There are exceptions - a heavy goldenrod year in a good location can leave a genuine surplus above winter needs - but the default is to leave it, and the exam expects the default.

Goldenrod honey is worth knowing sensorily. It is medium to dark amber, strongly flavored, and granulates quickly. While curing, a colony working goldenrod hard produces an unmistakable sour, socky, faintly rank smell that fills the apiary and that a beekeeper who has not met it before frequently mistakes for disease. It is the volatile fraction of the curing nectar, it disappears as the honey ripens and is capped, and the finished honey does not carry it at anything like that intensity. Knowing the smell prevents a false foulbrood alarm every September.

9.5.8 A note on titi

Two different shrubs in the region are called titi, and confusing them causes trouble.

Black titi or buckwheat tree (*Cliftonia monophylla*) blooms in early spring and is a genuinely useful early nectar and pollen source in the Gulf coastal areas.

Summer titi or swamp cyrilla (*Cyrilla racemiflora*) blooms later, in late spring into early summer, and is the plant that causes purple brood. That is the subject of the next section.

9.6 Toxic Nectars, Toxic Pollens and Poisonous Honeys

Three separate questions hide inside "is this plant toxic to bees," and keeping them apart is most of the skill: is it toxic to *brood*, is it toxic to *adult bees*, and is the resulting *honey* toxic to *humans*? A plant can be any combination of these.

9.6.1 Purple brood and titi

Purple brood is a brood disorder caused by larvae being fed nectar or honey from summer titi, *Cyrilla racemiflora*, during its bloom. Affected larvae take on a blue to purple discoloration - often most obvious along the gut - and larval mortality follows. It appears in the coastal plain and Gulf coastal parts of the region where the plant is abundant in wet areas, and historically it has been a severe periodic problem, in some years affecting a large fraction of colonies in an affected district.

The diagnostic signature is what matters:

- It **appears abruptly and simultaneously** in essentially all colonies in an affected area, which no infectious disease does.
- It **coincides exactly with the titi bloom** and ends when the bloom ends.
- The larvae are **discolored purple or blue**, which no brood disease produces.
- There is **no ropiness, no sunken perforated cappings, no adherent scale, no foul odor** - none of the signs of American or European foulbrood.

There is nothing to treat, because it is a poisoning rather than an infection. Where the problem is severe enough to matter, the management response is to move colonies out of heavy titi for the duration of the bloom. The larger value of recognizing it is negative: it stops a beekeeper from treating, from burning equipment, or from reporting a foulbrood outbreak that does not exist.

9.6.2 Buckeye

Buckeye (*Aesculus* species) is the other classic botanical brood disorder. Its nectar and pollen have long been associated with brood mortality and with adults emerging deformed - crumpled wings, missing or malformed legs and antennae - during the spring bloom. Adult bee mortality and queen problems have also been reported from heavy buckeye exposure. As with titi, there is no remedy other than moving colonies away from heavy stands for the bloom period, and, as with titi, the diagnosis rests on the coincidence with a specific bloom, the local abundance of the plant, and the absence of infectious disease signs.

The generic skill the exam is testing across both of these is the **differential diagnosis of a brood disorder with no infectious signs**. When brood is dying and there is no ropiness, no characteristic odor, no scale,

no mites of consequence and the queen is laying normally into cells that then fail, the candidate causes are: plant toxicity coinciding with a bloom; chilled brood, which kills a contiguous patch at the periphery and leaves intact bodies; pesticide exposure, which usually shows adult mortality at the entrance as well; and genetic brood failure such as diploid drone removal, which produces scattered empty cells rather than dead larvae. Timing against the bloom calendar is the cheapest discriminator available, and it is one more reason to keep a bloom calendar.

9.6.3 Honeys toxic to humans

The heath family supplies the classic case. Several *Rhododendron* species, mountain laurel (*Kalmia latifolia*) and their relatives produce **grayanotoxins** - diterpenes that bind voltage-gated sodium channels and keep them open. Honey made predominantly from such nectar causes the syndrome historically called mad honey poisoning: dizziness, nausea, salivation, blurred vision, weakness, and characteristically bradycardia and hypotension, occasionally severe enough to require medical support. Honey bees tolerate these nectars well enough to keep foraging on them (though laboratory work has found grayanotoxin harmful to honey bees at some nectar concentrations), which is exactly why the hazard exists: nothing in the colony filters it out.

In practice this is rarely a commercial problem in the southern Appalachian portion of this region. Mountain laurel and Catawba rhododendron bloom mainly in May and June and rosebay (great) rhododendron from June into July - late spring and early summer, later at higher elevations - when colonies are usually working other sources heavily, they seldom yield a large enough surplus to dominate a crop, and a beekeeper would have to be taking a substantial surplus from a stand of almost nothing else. But the mechanism is examinable, and so is the general principle: **the bee is not a toxicological filter.** Plant secondary compounds present in nectar - grayanotoxins, tutin in some other parts of the world, pyrrolizidine alkaloids from certain composites and borages - pass into honey largely unaltered.

The risk is practical only where these plants dominate the forage during that bloom, so management is a matter of knowing your forage. Know where the stands are and when they bloom. Harvest by flow, so that honey stored while laurel or rhododendron was the main source is kept separate rather than blended into the crop. Leave that honey on the colonies as stores rather than bottling it. And never sell honey of doubtful source, least of all labeled as a single-source honey. The cases that reach medical attention usually involve honey from a stand of little else, or honey sought deliberately for its effect; a candidate should be able to explain the hazard to a customer without either dismissing it or exaggerating it.

9.7 Why Honeys Differ: Color, Flavor and Granulation

9.7.1 Color

Honey color runs from water white to nearly black and is graded on the Pfund scale, in millimeters of the reference wedge. The USDA grade boundaries are worth knowing because they appear on bulk sales contracts and in extension publications:

Color grade	Pfund (mm)
Water white	8 or less
Extra white	over 8 to 17
White	over 17 to 34
Extra light amber	over 34 to 50
Light amber	over 50 to 85
Amber	over 85 to 114
Dark amber	over 114

Color comes from three sources. First, minerals: honeys higher in ash content are darker, and mineral content is a property of the nectar source and the soil it came from. Second, plant pigments and phenolics - flavonoids, phenolic acids and related compounds carried over from the nectar - which also account for most of the difference in antioxidant activity between light and dark honeys. Third, Maillard and caramelization reactions between the honey's sugars and its amino acids, which proceed slowly at room temperature and rapidly when honey is heated. That third pathway is why **any honey darkens with storage and with heating**, and why an over-heated light varietal loses both its color grade and its price.

The practical rule that follows is that light honeys command a premium on the table market and dark honeys generally do not, so the handling of a light crop - prompt extraction, minimal heat, fine but not aggressive filtration, cool storage - is worth real money on tupelo, sourwood and gallberry in a way it is not on poplar.

9.7.2 Flavor

Flavor is carried by a small volatile fraction - terpenes, aldehydes, alcohols, esters and phenolic degradation products - derived from the nectar and from the plant's own secondary chemistry. It correlates loosely with color: dark honeys are usually stronger. The correlation is not a rule, and sourwood, which is light amber and intensely flavored, is the regional counterexample.

Volatiles are fragile. They are lost to heat and to prolonged open handling, which is another argument for gentle processing of premium varietals, and they are the reason a sourwood or tupelo crop that has been heated for easy bottling sells as ordinary honey.

9.7.3 Granulation

Granulation is crystallization of **glucose monohydrate** out of a supersaturated solution. Honey is supersaturated with respect to glucose at ordinary temperatures - it holds far more sugar than water can dissolve at equilibrium - so crystallization is the thermodynamically favored state, and the question is only how fast it happens.

Three factors govern the rate.

Sugar composition. The glucose-to-fructose ratio is the primary driver, because fructose is far more soluble than glucose - roughly four times as much dissolves in a given weight of water at room temperature - and stays in solution. Equivalently and more precisely, the **glucose-to-water ratio** predicts behavior: at ratios below roughly 1.7 a honey tends to stay liquid for very long periods; around 2.0 granulation is expected within months; above roughly 2.1 it can be fast, sometimes granulating in the comb before extraction. Tupelo sits at the liquid end. Cotton, clover and many of the *Brassica* honeys sit at the fast end, and rapeseed or canola honey - not a regional crop but the textbook extreme - can set solid in the super.

Nucleation sites. Crystals need something to start on: pollen grains, fine wax particles, air bubbles, dust, scratches in the container, and above all pre-existing glucose crystals. This is why the last of a granulated batch seeds the next, why fine straining slows granulation relative to unfiltered honey, and why deliberately seeding with finely ground crystal is the basis of creamed honey. It is also why "raw" honey with more suspended solids generally sets faster than heavily filtered honey, all else equal.

Temperature. Crystallization is fastest in the range of about 55 to 60 degrees F, with roughly 57 degrees F the figure usually quoted. The rate falls off in both directions and for different reasons. Colder honey is more supersaturated - the driving force is greater - but viscosity rises steeply and the sugar molecules cannot migrate to the growing crystal faces, so below about 50 degrees F crystallization slows and deep cold nearly stops it. Warmer honey is less supersaturated, and above roughly 77 degrees F crystals begin to redissolve; sustained warmth around 95 to 100 degrees F will liquefy a set honey, at some cost in volatiles and HMF.

Three practical consequences:

- Fast-granulating honeys should be extracted promptly and not left in the super, because honey that sets in the comb will not come out in an extractor and must be melted or fed back.
- Fast-granulating honeys are the right raw material for creamed honey, which converts a defect into a premium product by controlling crystal size.
- Slow-granulating honeys command a premium as a liquid pack. Tupelo's price rests partly on this property.

A last point on which many beekeepers are wrong: **granulation is not spoilage and is not a sign of adulteration.** If anything it is weak evidence of authenticity, since many adulterated products are formulated to stay liquid. Fermentation is the actual spoilage risk, and it is a moisture and yeast question, not a crystallization question - though the two connect, because crystallization removes glucose and water from the liquid phase and raises the moisture of the remaining syrup, which is why a partly granulated honey at marginal moisture can ferment when the same honey would not have.

9.8 Floral Fidelity, Constancy, and What "Varietal" Actually Means

Varietal honey is possible because of a specific behavior: **an individual forager tends to work one plant species on a trip, and often across many consecutive trips, ignoring other rewarding flowers she passes.** This is floral constancy, and it is distinct from the colony's overall foraging profile. A colony at

any moment is typically working several species through different groups of foragers; each of those foragers is specializing.

Constancy makes sense for the bee. Handling a flower efficiently is a learned skill - which approach, where the nectar sits, how to trip the mechanism - and switching species means paying the learning cost again and handling flowers slowly for a while. Constancy also happens to be what makes the bee a good pollinator, because pollen deposited is conspecific pollen.

The mechanism is reinforced by recruitment. A dance recruits nestmates to a location and, through the odor carried on the dancer and in the sample she shares, to a scent. Recruits arrive primed for that odor. So a rich source in bloom pulls a large, self-reinforcing cohort of constant foragers onto one species, which is exactly what a varietal producer needs.

Constancy is not absolute. Bees switch when a source declines, when weather changes, when a better source is discovered, and generalist foragers exist alongside specialists. That is why a “monofloral” honey is a statement about predominance, not purity. Melissopalynology - counting pollen types in a honey sample - is the standard analytical check, and its conventional threshold is that the named source should be the predominant pollen type, often taken as 45 percent or more of the countable grains.

That threshold has to be applied with judgment, because pollen representation in honey is systematically biased. Some plants are nectar-rich and pollen-poor and are chronically under-represented; some are pollen-rich or have pollen that contaminates nectar heavily and are over-represented; and wind-borne pollen that no bee collected shows up in the count. Tupelo is a classic case where the pollen fraction and the nectar fraction do not track, which is one reason regional standards for it are set by convention rather than by a universal threshold.

The regulatory framing matters for labeling. FDA’s guidance on honey labeling takes the position that a floral source may be named on the label **if there is information supporting that the named plant is the chief floral source of the honey.** That is a substantiation standard, not a percentage: bloom timing, apiary location, the discipline of the harvest, sensory characteristics and pollen analysis all count as information. It also means a beekeeper who runs mixed supers through the season and then calls the result sourwood because sourwood grows nearby has a labeling problem, not merely a marketing exaggeration.

9.8.1 The discipline that produces a varietal, and the same discipline that prevents off-flavors

Varietal production is a harvest-scheduling problem:

- Know the bloom sequence at the site well enough to predict the target flow within a week or so.
- Remove and extract everything on the colony before the target bloom opens, so the supers going on are clean.
- Put drawn comb on for the target flow - drawn comb rather than foundation, since a short flow will not both draw comb and fill it.
- Pull promptly at the end of the bloom, before the next source dilutes it.

- Extract, keep the crop segregated through settling and bottling, and taste it.

The identical discipline solves the off-flavor problem, which is why it pays twice. A beekeeper who accumulates honey through the whole season in the same supers and extracts once in autumn gets a blend of everything that bloomed, and if anything that bloomed was strongly flavored, the whole crop carries it.

Regional sources of off-flavor worth knowing:

- **Bitterweed or sneezeweed** (*Helenium* species) of pastures, roadsides and disturbed ground, which imparts a genuinely bitter flavor. It is the classic answer when a beekeeper reports a bitter crop.
- **Privet**, which produces a strongly flavored honey many table buyers dislike, sometimes described as sharp or medicinal.
- **Goldenrod and aster**, whose autumn crop is strongly flavored and which carry the curing smell described earlier.
- **Onion and other *Allium***, near seed production or gardens, which taints unmistakably.
- **Buckwheat and other dark, strong sources** where they occur, which are excellent honeys to those who like them and unsellable to a customer expecting clover.

The management answers are: harvest by flow rather than by calendar; keep crops segregated; taste every batch before blending or bottling; and hold a strongly flavored crop aside for the baking trade, for mead, or simply leave it on the colonies as winter stores, where the bees will not object to it.

9.9 Invasive Nectar Sources: The Honest Position

Two invasive plants are significant nectar sources in this region, and both put beekeepers in an awkward position.

Chinese privet (*Ligustrum sinense*) is dominant in riparian forests, fencerows, old fields and forest edges across much of the region, forming dense thickets that shade out the understory. It blooms in mid to late spring, heavily and with a strong scent, and it produces a real crop in some districts - though the honey is strongly flavored and not to every buyer's taste. Its ecological cost is well documented: removal experiments in riparian forest have found significant increases in native bee abundance and diversity following privet removal, which is a particularly pointed result, since it shows that the plant which feeds honey bees is suppressing the native pollinator community.

Chinese tallow (*Triadica sebifera*) is a fast-growing tree of the Gulf coastal areas that forms near-monocultures on wet ground and along waterways. It blooms in early summer, and in the districts where it is abundant it is a major honey plant - the honey light in color and reasonable in quality, granulating fairly quickly - and in some places it has been the principal summer crop. It has also displaced enormous areas of native coastal prairie and bottomland, and proposals to release biological control agents against it have produced real friction with beekeepers who depend on it.

The examinable position is a compound one, and both halves must be stated:

The first clause is true. These plants do produce nectar, bees do work them, and beekeepers in those landscapes do get crops from them. Pretending otherwise to seem ecologically responsible is dishonest and beekeepers will not believe you.

The conclusion does not follow. Their value to a beekeeper does not offset their ecological cost and does not license planting, propagating or spreading them. Both are regulated as noxious or invasive in parts of the region, and planting them may be unlawful as well as unethical.

The defensible practice is straightforward: a beekeeper may work a flow from an invasive already present in the landscape without apology, while still supporting its control, never planting or propagating it, and never arguing against a control program on the grounds that it would cost a honey crop. A master-level candidate is expected to hold both facts at once and to be able to explain the distinction to a beekeeping audience that may not want to hear it, and to a conservation audience that may not believe a beekeeper will say it.

9.10 Planting for Bees, Honestly Assessed

Beekeepers are asked constantly what to plant for bees. The honest answer requires arithmetic before botany.

A colony consumes a great deal. Estimates vary widely with climate and management, but the commonly cited working figures are on the order of 120 to 175 pounds of honey and 33 to 55 pounds of pollen consumed per colony per year, with much of the honey burned simply keeping the colony alive rather than converted into anything the beekeeper sees. Against that, a quarter-acre wildflower planting - a serious undertaking for a homeowner - supplies a tiny fraction of one colony's annual requirement, and it supplies it during whatever weeks it happens to bloom.

Now the landscape side. The foraging area around an apiary is thousands of acres. A planting measured in fractions of an acre is, in strict nutritional terms, a rounding error.

That is not an argument against planting, but it does change what planting is for:

- **Diversity and timing beat quantity.** A small planting chosen to bloom in the local dearth, or to supply pollen in late winter or early autumn, does something a small planting that blooms in mid spring - alongside a thousand acres of *Rubus* - does not. Pollen diversity in particular has measurable effects on bee physiology at quantities far below what a flow requires.
- **Native and unimproved varieties over showy cultivars.** Double-flowered and heavily bred ornamentals are frequently nectarless or nearly so.
- **Never an invasive.** See the previous section.
- **The pesticide question comes with the plant.** Nursery stock treated with systemic insecticides can make a pollinator planting a hazard rather than a resource.

The much larger lever is **land management rather than planting**, because it operates at landscape scale for little or no cost:

- Prescribed fire and thinning that maintain an open pine understory, which is what maintains gallberry and the flatwoods bloom generally.
- Mowing regimes on roadsides, rights-of-way and field margins timed to let *Rubus*, clover and the summer and autumn composites flower rather than cutting them in bud.
- Retaining fencerows, hedgerows, stream buffers and odd corners instead of clearing to the edge.
- Grazing and pasture management that permits clover to flower.
- Cover crops chosen to bloom, where the cropping system allows it.
- Not converting open land with a working understory into closed plantation or pavement.

And the largest lever available to the individual beekeeper is neither planting nor management but **siting**. Moving an apiary two miles to a location with a better bloom sequence changes the forage available to those colonies by more than any planting that beekeeper will ever do. Master-level advice on "what should I plant" ought to begin by asking what is already within flight range, when it blooms, and where the gaps are.

9.11 Learning a Local Bloom Calendar

The last item in this domain is methodological, and it is the one that makes the rest usable.

Start with what exists. The regional Extension nectar-flow calendar and the collective experience of the local beekeeping association give a framework and rough dates. Both are averages over an area larger than your foraging radius, so treat them as a hypothesis.

Then observe your own two to three miles. The work is unglamorous and cumulative:

- Record first bloom, peak bloom and end of bloom for every major plant within about two miles, every year. Peak matters more than first bloom, because a scattered first flower does not make a flow.
- Photograph and identify what you do not know. A plant you cannot name is a plant you cannot predict.
- Record incoming pollen colors and match them to sources, which tells you what the bees are actually working rather than what is merely in bloom. Bees frequently ignore a plant that a list says they should use.
- Keep weight records. A hive scale under one colony, read consistently, converts impressions into data and is the single most informative instrument in an apiary. Continuous-weight work such as Meikle and Holst's review of hive scale methods shows how much of a colony's behavior - daily forage gain, dearth, robbing, swarming, the start and end of a flow to the day - is visible in the weight trace. Consistent hefting and a notebook is a poor substitute but a real one.
- Correlate with weather, not with dates. Note temperature, rainfall in the preceding weeks, and any late freeze. Bloom in this region shifts by weeks between years; the sequence is what repeats.

Understand the spatial shifts. Hopkins' bioclimatic law, the old rule of thumb, puts spring bloom later by roughly four days for each degree of latitude northward, each five degrees of longitude eastward, and each 400 feet of elevation gained. It is approximate and modern phenology data show real departures from it, but it captures the right structure for this region: the coastal plain runs weeks ahead of the mountains, and within the mountains a cove runs ahead of a ridge. Beekeepers move colonies up in elevation to follow a flow for exactly this reason, and a sourwood producer plans around it.

Talk to established local beekeepers, and weight what they say by how long they have kept bees in that specific spot and whether they keep records. Local knowledge is genuinely the best available source on flows, and it is also where folklore concentrates.

The most valuable output is not the list of flows. It is the identification of the **dearth periods**. The flows tell you when to super, which is a decision with a wide margin for error - a super on two weeks early costs nothing. The dearths tell you when to feed, when robbing risk peaks, when to close entrances down, when beetle pressure will build, when a split will fail for lack of forage, when queens will mate poorly, and when supers will be off so the mite treatment window opens. Those are the decisions with narrow margins and expensive failure modes. A beekeeper who knows their dearth calendar cold and their flow calendar only approximately will do better than the reverse.

9.12 Numbers to Know Cold

Figure	Value	Why it is that value
Nectar sugar concentration preferred by foragers	About 30-50 percent; largely ignored below about 10-15 percent	Below that, the energy cost of carrying and evaporating the water approaches or exceeds the return
Nectar to honey conversion	Roughly 2 lb of 40 percent nectar per 1 lb of honey; over 4 lb if the nectar is 20 percent	Finished honey is about 17 percent moisture; the difference is water the colony must evaporate
Honey moisture, safe storage	About 18.6 percent or below for extracted honey; below about 17.1 percent will not ferment within a year regardless of yeast count	Osmotic pressure and water activity control osmophilic yeast growth
Average US honey composition	About 38 percent fructose, 31 percent glucose, 17 percent water, 7 percent maltose, 1 percent sucrose	White's USDA survey of 490 floral honeys; fructose:glucose ratio about 1.2
Glucose-to-water ratio and granulation	Below about 1.7, stays liquid a long time; near 2.0, granulates in months;	Glucose monohydrate is what crystallizes; it is far less soluble than fructose

Figure	Value	Why it is that value
	above about 2.1, can be fast	
Temperature of fastest crystallization	About 55-60 degrees F, roughly 57 degrees F	Below that, viscosity blocks molecular migration; above it, supersaturation falls and crystals begin to redissolve above about 77 degrees F
Pfund color grades	Water white 8 mm or less; extra white to 17; white to 34; extra light amber to 50; light amber to 85; amber to 114; dark amber above 114	USDA grading standard; color tracks mineral and phenolic content and darkens with heat and age
Tulip poplar first flowering	Usually 15-20 years of age	Nectar is discretionary photosynthate; a small suppressed tree does not flower or does not yield
Tulip poplar nectar, single young tree	On the order of 8 lb nectar (about 4 lb honey) per season in one old report	One tree in one year; use as an order of magnitude, not a constant
Tupelo bloom window	Roughly 2-3 weeks, early to mid spring	A narrow window bracketed by titi and willow before and gallberry after, which is why supers must be clean going in and pulled promptly
Sourwood elevation	Poor production below roughly 1,000 ft; improves with elevation	Nectar yield is tied to the mountain environment, not merely to the tree's presence
Sourwood bloom	Early summer, after the main spring flow has ended	Which is what makes it valuable: it fills a slot that would otherwise be dearth
Gallberry bloom	Late spring into early summer	Overlaps the tail of poplar and *Rubus*; dependent on open, burned flatwoods
Foraging area, 2-mile radius	About 12.5 square miles, roughly 8,000 acres	Area scales as the square of radius; a 3-mile radius is about 18,000 acres
Colony annual consumption	On the order of 120-175 lb honey and 33-55 lb pollen (estimates, widely variable)	The benchmark against which any "planting for bees" proposal must be measured
Melissopalynology threshold for monofloral	Predominant pollen type, conventionally 45 percent or more	A predominance standard, not purity, and biased by over- and under-represented pollens
FDA floral-source labeling standard	Name a source if there is information supporting that it is the chief floral source	A substantiation standard, not a fixed percentage

Figure	Value	Why it is that value
Hopkins' bioclimatic law	About 4 days later per degree of latitude north, per 5 degrees of longitude east, per 400 ft of elevation	A rule of thumb for how bloom shifts across the region; approximate, not predictive to the day
Build-up lead time before a flow	6-8 weeks of protein availability ahead of the target bloom	Foragers for the flow must be reared before it, and the nurses that rear them fed before that
Purple brood onset	Abrupt, simultaneous across all colonies in an affected area, coinciding with summer titi bloom	A poisoning, not an infection; infections spread colony to colony over weeks
Pine pollen protein value	Low; functionally filler	Wind-pollinated species are not selected to feed insects; evaluate a pine site on its understory
Corn	No nectar; abundant pollen of mediocre protein quality	Wind-pollinated; the exposure risk is that it is not treated as a bee-attractive crop

9.13 Common Misconceptions

Misconception: If the flow is on, I will notice and can get supers on in time. **Correction:** Not with tulip poplar. It opens early, yields hard for roughly two to three weeks, and by the time a beekeeper has noticed the weight gain and driven back with supers, a third of the crop is over and the bees have backfilled the brood nest, which triggers swarming. Supers go on before the bloom, based on the calendar and the buds, not after it.

Misconception: The plant list says this species is a major honey plant, so a stand of it should give a crop. **Correction:** Nectar secretion varies with genotype, plant age and vigor, soil moisture, temperature, humidity and stress. The same stand can yield heavily one year and nothing the next. A published list tells you what is possible; only your own weight records tell you what is probable at your site.

Misconception: More colonies on a good site will take more of the crop, since the plants keep producing as long as bees keep working them. **Correction:** Removal does not stimulate replacement at any scale that matters. The nectar available within flight range in a season is essentially fixed, so adding colonies divides a fixed resource. This is the whole concept of apiary carrying capacity, and overloading a site shows up as every colony making a mediocre crop rather than as more total honey.

Misconception: Corn offers nothing to bees, so spraying it or treating its seed poses no risk to colonies. **Correction:** Corn offers no nectar and enormous quantities of pollen, which bees collect heavily during tasseling. Add the abraded neonicotinoid seed-treatment dust exhausted by pneumatic planters, which drifts onto nearby flowering vegetation, and corn acreage becomes a real exposure pathway precisely because nobody thinks of it as bee-attractive.

Misconception: Cotton is only a risk to bees when it is in bloom. **Correction:** Cotton bears extrafloral nectaries on leaves and bracts The leaf nectaries secrete modestly all season, and the bract nectaries secrete heavily from squaring through boll development and after the flower has fallen. Bees can work a cotton field with few or no open flowers. This is the single most useful specific point a beekeeper can raise with a cotton grower planning an application.

Misconception: Pine country is good bee country because there is so much pine pollen in spring. **Correction:** Pine pollen is low-value protein that no colony builds on, and pines give no nectar. A pine-dominated site is worth exactly what its understory and surrounding land are worth - excellent if it is open, burned flatwoods with gallberry, close to worthless if it is a closed-canopy plantation.

Misconception: Purple brood is a disease and should be treated, or reported as a possible foulbrood. **Correction:** It is a plant toxicosis from summer titi nectar fed to larvae. It appears abruptly and simultaneously in every colony in an area, coincides exactly with the bloom, produces purple to blue larvae, and shows none of the ropiness, odor, sunken cappings or scale of foulbrood. There is nothing to treat; where it is severe, move colonies for the bloom.

Misconception: Honey bees will not work a plant whose nectar is toxic, so a poisonous honey cannot really happen. **Correction:** Bees have no general mechanism for detecting plant secondary compounds that are harmful to humans or to brood. Grayanotoxins from *Rhododendron* and mountain laurel pass into honey essentially unaltered and affect people far more obviously than bees. Titi nectar and buckeye poison brood while foragers work them willingly. The colony is not a toxicological filter.

Misconception: Tupelo honey stays liquid because of how it is processed or filtered. **Correction:** It stays liquid because of its sugar chemistry - an unusually high fructose fraction relative to glucose, and therefore a low glucose-to-water ratio. Glucose is the sugar that crystallizes. Processing affects nucleation and can modestly delay granulation in any honey, but it cannot give an ordinary honey tupelo's behavior.

Misconception: Granulated honey has gone bad, or shows it was adulterated or over-heated. **Correction:** Granulation is spontaneous crystallization of glucose monohydrate from a supersaturated solution and is the natural fate of most honeys. If anything it is weak evidence of authenticity. The genuine spoilage risk is fermentation, which is a moisture and yeast problem - and one that partial granulation can worsen, since crystallizing glucose raises the moisture of the liquid phase that remains.

Misconception: Goldenrod honey should be harvested like any other crop; it is a fall flow. **Correction:** In most of this region the fall goldenrod and aster bloom is the colony's winter feed and, more importantly, the protein that produces physiologically competent winter bees. Taking it and replacing it with sugar syrup returns the calories and none of the protein. Treat it as nutrition; harvest only a genuine surplus above winter requirement.

Misconception: That sour, socky smell in the apiary in autumn means disease in the yard. **Correction:** It is curing goldenrod nectar. The volatiles that produce it dissipate as the honey ripens and is capped, and the finished honey does not smell like that. It is one of the most reliable signals in regional beekeeping that a fall flow is on.

Misconception: Privet and tallow feed my bees, so they cannot be all bad and I should be able to defend them. **Correction:** They do feed bees and they are still serious invasives. Privet removal experiments in riparian forest have shown increases in native bee abundance and diversity after the plant is taken out, so the plant that supplies a honey crop is suppressing the wider pollinator community. Work the flow if it is there; do not plant, propagate, or argue against control.

Misconception: Planting a pollinator garden will meaningfully feed my colonies. **Correction:** A colony consumes on the order of a hundred-plus pounds of honey and dozens of pounds of pollen a year, and forages over thousands of acres. A small planting is a rounding error nutritionally. Its real value is timing and diversity - blooming in your dearth, or supplying late-winter or autumn pollen. The big levers are land management at landscape scale, and apiary siting.

Misconception: Sourwood or tupelo is a matter of management; with clean supers and good timing a beekeeper anywhere in the region could produce it. **Correction:** Both are determined by the landform. Tupelo is a river-swamp crop of a few river systems of the coastal plain, from South Carolina to northwest Florida; sourwood is a crop of the mountains and foothills, mostly above about a thousand feet. Discipline is necessary for either crop and is nowhere near sufficient. Geography is the first filter.

Misconception: Once I know my flow dates I have learned the local calendar. **Correction:** The dearths carry the expensive decisions. Flows tolerate error - an early super costs nothing. Dearths determine feeding, robbing risk, beetle pressure, split timing, mating success and the mite-treatment window, and every one of those has a narrow margin and a costly failure.

9.14 Self-Check Questions

- Explain why the arrival of the tulip poplar bloom exposes a beekeeper who is working from a northern management calendar, and describe the specific decisions that must have been made before the bloom opens.
- Distinguish the pollen value of a plant from its nectar value, using corn and cotton as your two examples. Explain why each matters for pesticide risk.
- Define an extrafloral nectary, state its usual ecological function, and explain the specific argument a beekeeper should make to a cotton grower planning a mid-season insecticide application.
- A beekeeper in the coastal plain of the region asks why they cannot produce sourwood honey despite having clean supers and good timing. Answer them.
- Name the species that yields commercial tupelo honey, state where it grows and when it blooms, and explain in chemical terms why the honey resists granulation. Then describe two features of the production system that make the crop risky.
- A colony’s brood suddenly shows purple to blue larvae with elevated mortality, and every other colony in the yard and in neighboring yards shows the same thing in the same week. Give your diagnosis, the reasoning that excludes infectious disease, and your management response.

- List the factors that govern nectar secretion, and explain why this is the reason a published plant list is a weaker planning tool than a hive scale.
- Why does gallberry production depend on forestry practice? Generalize the principle to two other regional situations.
- A beekeeper reports that their extracted crop has an unpleasant bitter flavor. Give two plausible botanical causes for this region, and describe the harvest discipline that prevents the problem. State why that same discipline pays a second dividend.
- Explain what determines whether a honey granulates quickly or slowly, naming the controlling ratio and the two other factors that affect the rate. Name a regional honey at each end and give one commercial consequence for each.
- A beekeeping association asks you to speak about invasive plants. Chinese privet supplies a significant crop for several members. State the position you would take and justify both halves of it.
- Explain why early-season pollen matters more than early-season nectar for colony build-up, and describe what a beekeeper should watch and do in the six to eight weeks before the main flow.
- A landowner offers you a yard in the middle of a fifteen-year-old closed-canopy pine plantation. What do you need to know before accepting, and what is the arithmetic behind the area you should be assessing?
- Describe how you would build a bloom calendar for a new location over three seasons, and state what the most valuable product of that effort is and why.

9.15 Self-Check Answers

- Tulip poplar opens in mid spring and yields heavily for roughly two to three weeks. A colony can only work it if it already has a large foraging force, and foragers take about five to six weeks from egg to field bee, so the build-up decisions - feeding, protein availability, equalizing, disease and mite management - had to be taken six to eight weeks earlier, in late winter. Supers must be in place before the first flowers open, because backfilling of the brood nest during a strong flow with no storage space is a primary swarm trigger and because unstored nectar is lost income. A beekeeper who supers in May, on a northern schedule, arrives after the crop and after the swarms.
- Corn is wind-pollinated: no nectar at all, but enormous quantities of pollen of mediocre protein quality that bees collect heavily at tasseling. Cotton is the mirror image: a real nectar source through both floral and extrafloral nectaries, but pollen that is large, spiny and sticky and that bees pack poorly. For pesticide risk the point is identical in both cases - a crop's attractiveness cannot be judged from whether it looks like a pollinator crop. Corn gets treated as bee-irrelevant while bees work it for pollen and while planter dust drifts onto nearby bloom; cotton gets treated as safe when not blooming while bees work its leaves and bracts.
- An extrafloral nectary is a nectar-secreting structure outside the flower - on leaves, petioles, stipules or bracts - and not involved in pollination; its usual role is to recruit ants and predatory arthropods that defend the plant against herbivores. The argument to a cotton grower is

concrete: cotton secretes nectar from the underside of the leaves and from the bracts around the buds and bolls, heavily from squaring through boll development and after the flower has fallen, so bees can be present in a field with few or no open flowers. Therefore the pollinator precautions that would apply at bloom - spraying early morning or evening, choosing less hazardous products, notifying nearby beekeepers - should apply outside bloom too.

- Sourwood is a tree of the southern Appalachian mountains and foothills, and its nectar yield is strongly tied to elevation; production is poor below roughly a thousand feet and improves with height. On the coastal plain the tree is largely absent, and where individuals occur they do not yield a crop. Varietal discipline - clean supers placed specifically for the bloom after spring honey is off, pulled promptly - is necessary to produce marketable sourwood but cannot create the resource. The general rule is that a regional varietal is defined by a landform first and by management second.

- Ogeechee tupelo, *Nyssa ogeche*, in river swamps of the coastal plain from South Carolina to northwest Florida, with the commercial crop concentrated on a few river systems such as the Apalachicola, blooming in early to mid spring over a window of roughly two to three weeks. It resists granulation because granulation is crystallization of glucose monohydrate, and tupelo carries an unusually high fructose fraction relative to glucose; with a low glucose-to-water ratio there is not enough glucose to nucleate and grow crystals at ordinary storage temperatures. The risks: the bloom is bracketed by titi and willow before and gallberry after, so supers must be clean going in and pulled immediately afterward or the varietal is lost; and the crop sits in a floodplain, so a river rise or bad weather across a two-to-three-week window can take the entire year's production.

- Purple brood, caused by larvae being fed nectar of summer titi, *Cyrilla racemiflora*. Infectious disease is excluded by the pattern and the signs: infections spread colony to colony over weeks rather than appearing simultaneously across a district; and the brood shows none of the ropiness, sunken and perforated cappings, adherent scale or characteristic odor of American or European foulbrood. The purple to blue discoloration itself is not produced by any brood pathogen. Confirmation comes from the coincidence with the titi bloom and the local abundance of the plant, and from the disorder ending when the bloom ends. There is nothing to treat; where losses are serious, move colonies out of heavy titi for the duration of the bloom.

- Species and genotype, including cultivar; plant age, size, vigor and canopy position; soil moisture and recent rainfall; temperature, including night temperatures during bloom; humidity, which sets concentration; wind, aspect and elevation; plant stress from pests, disease or nutrient limitation; and time of day and flower age. Because all of these vary year to year, the same stand of the same species can give a surplus one season and nothing the next. A plant list encodes only the first variable and none of the others, so it predicts what is possible rather than what will happen. A hive scale measures the outcome of all of them at once, at your site, and converts impressions into dated records you can plan from.

- Gallberry is a fire-adapted shrub of open pine flatwoods; it resprouts vigorously after burning and flowers best in a sunlit understory. Frequent low-intensity prescribed fire maintains that structure. Fire suppression, canopy closure, dense plantation forestry, herbicide release and land conversion all remove it. So the crop tracks forestry practice rather than climate or soils. Two parallels: clover honey depends on grazing and pasture management that lets clover

flower; roadside and right-of-way bloom, including *Rubus*, depends entirely on mowing timing and herbicide use by whoever maintains the corridor.

- Bitterweed or sneezeweed, *Helenium* species, of pastures and disturbed ground, is the classic cause of a genuinely bitter crop; a strongly flavored source such as privet, or an autumn goldenrod and aster crop, is the other common explanation for an unpleasant or weedy flavor. Prevention is harvesting by flow rather than by calendar: know the local bloom sequence, remove and extract at the end of each distinct flow instead of accumulating honey in the same supers all season, keep crops segregated, and taste every batch before blending or bottling, holding strong honey aside for baking or leaving it for winter stores. The second dividend is that this is exactly the discipline that makes varietal production possible, so the same practice both protects the table crop and creates the premium one.

- The controlling factor is the sugar composition, best expressed as the glucose-to-water ratio: below roughly 1.7 a honey stays liquid for long periods, near 2.0 it granulates within months, above roughly 2.1 it can set quickly, because glucose monohydrate is what crystallizes and glucose is much less soluble than fructose. The other two factors are nucleation sites - pollen, wax particles, air bubbles and above all existing crystals - and temperature, with crystallization fastest around 55 to 60 degrees F and slowed by both colder, more viscous conditions and warmer, less supersaturated ones. Tupelo is the regional slow example and commands a premium as a liquid pack; cotton is a fast example and should be extracted promptly and is a good candidate for creamed honey.

- The position has two halves that must both be stated. First, the factual half: privet and Chinese tallow genuinely are nectar sources, bees work them, and members do take crops from them - denying this destroys credibility with the audience. Second, the conclusion that does not follow: their value to beekeepers does not offset their ecological cost and does not license planting or propagating them. Privet forms dense riparian thickets that suppress the native understory, and removal experiments have found native bee abundance and diversity increase after it is taken out - so the plant feeding honey bees is displacing the wider pollinator community. The practical line: work a flow from an invasive already present without apology, never plant or spread it, and do not oppose control programs on the grounds of a honey crop.

- The colony normally still holds honey, and where it does not the beekeeper can feed syrup, which substitutes directly for nectar. There is no equivalent protein reserve: stored beebread is finite and the winter bees' fat-body and vitellogenin stores maintain those bees rather than supplying large-scale brood rearing. Brood food is secreted by nurse bees' hypopharyngeal and mandibular glands, and those glands require dietary protein, so incoming pollen is what permits and sustains brood nest expansion. In the six to eight weeks before the main flow the beekeeper should watch incoming pollen loads as the signal that build-up has started, ensure protein is available from natural forage or a substitute, and make sure the colony has stores or is fed so that expansion is not checked by a cold snap.

- The canopy species tells you almost nothing. You need to know the understory - is it open and periodically burned with a gallberry layer, or closed and swept bare - and what lies in the surrounding two to three miles: cutover with *Rubus*, rights-of-way, stream buffers, pasture with clover, poplar-bearing hardwood coves, row crops and their spray and planting schedules, and the presence of water. A fifteen-year-old closed-canopy plantation is close to a biological desert on its own, so the site stands or falls on its surroundings. The arithmetic: a two-mile foraging

radius encloses about 12.5 square miles or roughly 8,000 acres, and a three-mile radius about 18,000 acres, so the honest unit of assessment is thousands of acres rather than the stand you are standing in.

- Begin with the regional Extension nectar-flow calendar and the local association's experience as a hypothesis. Then, each season, record first, peak and end of bloom for every major plant within about two miles; photograph and identify what you cannot name; log incoming pollen colors and match them to sources so you know what bees are actually working rather than what is merely blooming; keep hive weight records, ideally with a scale under one colony, so gains and losses are dated against the bloom sequence; and correlate everything with weather - rainfall in the preceding weeks, late freezes, night temperatures - rather than with fixed dates, since bloom shifts by weeks between years and with elevation and latitude. The most valuable product is the map of the dearth periods, because those determine feeding, robbing risk, beetle pressure, split and mating timing, and when supers are off so the mite treatment window opens - the decisions with the narrowest margins.

9.16 Further Reading

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- Morse, R. A. and Flottum, K. (eds.). *Honey Bee Pests, Predators, and Diseases*, 3rd edition. A. I. Root, 1997. The chapter on plant poisoning is the fullest treatment of titi and buckeye available in the standard literature.

- Sanford, M. T. and Ellis, J. D. *Beekeeping: Florida Bee Botany*, University of Florida IFAS Extension (EDIS publication CIR686). The reference on coastal plain, flatwoods and Gulf coastal honey plants, including gallberry, titi and tupelo.

- University of Georgia Cooperative Extension Bulletin 1045, *Honey Bees and Beekeeping*, and associated UGA honey plant and nectar flow publications.

- Clemson Cooperative Extension and NC State Extension apiculture publications on nectar flow calendars and sourwood production; NC State Extension Gardener Plant Toolbox for identification of *Ilex glabra*, *Ilex coriacea* and *Cyrilla racemiflora*.

- Auburn University and Alabama Cooperative Extension System apiculture publications, including their treatment of Hopkins' bioclimatic law for estimating bloom times.

- LSU AgCenter apiculture publications, including their material on purple brood and on Gulf coastal nectar sources.

- USDA NRCS Plant Guides and the Forest Service Fire Effects Information System (FEIS) species reviews, for *Ilex glabra*, *Ilex coriacea*, *Cyrilla racemiflora*, *Oxydendrum arboreum*, *Nyssa ogeche* and *Triadica sebifera* - bloom periods, habitat, fire response and management.

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Chapter 10. Brood Diseases – Bacterial & Fungal

Covers exam questions Q176-Q198.

10.1 Orientation

Every question in this domain reduces to one of three ideas, and a candidate who holds all three can reason their way through items they have never seen.

The first is **the spore**. *Paenibacillus larvae* makes a spore that survives for decades in wax, honey and wood; *Melissococcus plutonius* makes none. That single difference determines everything downstream. Where the pathogen persists in the material, management must be directed at the material - destruction, irradiation, heat - because no manipulation of the colony reaches the reservoir. Where the pathogen does not persist in a durable form, management can be directed at the colony: better nutrition, a brood break, fresh comb. American foulbrood and European foulbrood are frequently taught as a matched pair of bacterial brood diseases, which encourages the assumption that they are managed as a pair. They are not, and the examiner knows it. Everything that separates them flows from the spore.

The second is **when the larva dies relative to capping**. A larva that dies uncapped is visible, is available to nurse bees for removal, and leaves remains that lie where the bees and the beekeeper can see them. A larva that dies after capping decomposes inside a sealed cell, and the cell's capping deforms as the contents shrink and the workers begin to chew through. Sunken, darkened, perforated cappings are not a separate sign from post-capping death - they are the same fact seen from outside. American foulbrood, sacbrood and chalkbrood kill after capping and give you capping signs. European foulbrood generally kills before capping and gives you visible larvae in open cells. Learn to derive the appearance from the timing rather than memorizing lists.

The third is **the pattern of mortality**, which is the discriminator between infectious and environmental causes and which the exam tests in the form of a reversal that catches a surprising number of candidates. Chilling kills whatever occupies the chilled zone - eggs, young larvae, sealed pupae, all of it - and stops at the edge of that zone, so it produces a bounded, contiguous patch of uniform mortality. Infection kills according to which individual received an infective dose at the susceptible age, which is a probabilistic business, so it produces mortality scattered through the brood area among perfectly healthy neighbours. Bounded and indiscriminate means environment. Scattered and selective means pathogen.

Layered over all three is the governing operational principle of the chapter: **the consequences of error are asymmetric**. Treating a case of European foulbrood as though it might be American foulbrood costs a few days of inconvenience, a tool wipe and a lab fee. Treating a case of American foulbrood as though it were something milder costs the apiary, and possibly the neighbours' apiaries as well. There is no symmetrical decision to be made here, which is why the correct response to suspicion is not more confident field diagnosis but containment plus laboratory confirmation. A master-level candidate is expected to reach for that structure automatically.

10.2 American Foulbrood: The Spore Is the Disease

Paenibacillus larvae is a Gram-positive, rod-shaped, spore-forming bacterium, and it is the only brood pathogen of honey bees that is classed as a notifiable or regulated disease across most of the United States. The organism's life history is brutally simple and every element of it has a management consequence.

10.2.1 Only the spore infects

The vegetative rod - the growing, dividing form that consumes the larva - is not infective. It cannot start a new infection; exposed to air, to the hive environment, to another larva's gut, it simply dies. Only the spore initiates disease. This is not a technicality. It means that an infected larva is harmless until its vegetative bacteria sporulate inside the dying body, and it means that every control measure that targets vegetative cells - notably antibiotics - operates on a stage that is not the transmissible one.

10.2.2 The window of susceptibility is about a day

A larva is susceptible only in the first day or two after it hatches from the egg. The experimental figure is that larvae cannot be infected later than about 53 hours after hatching, and susceptibility is far higher at the front of that window than at the back. Two mechanisms are usually invoked. The young larva's midgut is not yet fully lined by a mature peritrophic membrane, which later forms a physical barrier between gut contents and the epithelium the bacterium must cross. And the very young larva is fed a diet that is almost pure glandular secretion, which is subsequently diluted with honey and pollen as the larva ages - changing both the chemistry of the gut environment and the route by which contaminated material arrives.

The practical translation is that **American foulbrood is a brood disease with no adult signs at all**. Adults are not susceptible. An adult bee that ingests millions of spores is unharmed and continues to work. This is why a colony with an advancing infection can look entirely normal from the outside: entrance traffic is normal, foraging is normal, the bees are normal. What is happening is that a growing proportion of larvae are dying in their cells, and the adult population only begins to fall once brood mortality has run long enough that replacement fails. By the time entrance activity tells you anything, the colony has been distributing spores for months. An assessment of American foulbrood risk based on colony vigour or entrance activity is worthless, and this is the substantive reason that regular, careful, cell-by-cell brood inspection in good light is a biosecurity practice rather than a formality.

10.2.3 The infective dose is absurdly small

Laboratory determination of the median infective dose for young larvae puts it at fewer than ten spores - figures around 8 or 9 spores are the standard citations, with larvae under a day old infected by even less. Set that beside the output figure and the arithmetic becomes the whole story of the disease.

10.2.4 A single scale holds a billion spores or more

A single infected larva, decomposed to a dried scale, contains on the order of a billion spores; figures up to roughly 2.5 billion per scale are commonly quoted. Divide by an infective dose of ten and one scale represents enough inoculum to infect something like a hundred million larvae. There is no colony on

earth that rears a hundred million larvae. One scale, in other words, is not a trace of past disease. It is an inoculum vastly larger than an entire apiary could consume.

10.2.5 The spores last decades

Spores remain viable for decades: 35 years or more in dry scale in comb and woodenware, and more than seventy years for purified spores; in honey and other hive products survival is typically measured in years to decades. They tolerate desiccation, they survive the temperatures used in normal honey processing, and they are unaffected by freezing or by ordinary detergents. Combine this with the previous two figures and the conclusion is forced: **no practical cleaning process removes spores from drawn comb, and no colony-level intervention resolves the disease.** You are not managing a sick colony; you are managing contaminated material that happens to contain bees.

10.2.6 Adults distribute the spores internally

Nurse bees, house bees and robbers move spores everywhere - into brood food, into stored honey, onto comb surfaces, onto the beekeeper's gloves and hive tool. Within a colony, spores are effectively everywhere from an early stage, well before clinical signs are visible in the brood. Between colonies, the vectors are robbing, drifting, and above all the beekeeper: a hive tool carried from one colony to the next, a frame of brood moved to equalize, a super of honey redistributed, a box of used equipment bought at auction.

10.2.7 Genotypes and the tempo of disease

Five genotypes of *P. larvae* are distinguished by rep-PCR and labelled ERIC I to ERIC V, though only ERIC I and ERIC II are routinely recovered from field outbreaks. They differ in tempo. ERIC I kills the larva slowly, around twelve days after infection, which places death well after capping and produces the textbook picture of ropy remains under perforated cappings. ERIC II kills faster, in about seven days, and most larvae die before capping, so nurse bees can remove many of them before the bacterium has sporulated. This has been proposed as one reason ERIC II outbreaks can be less conspicuous and ERIC I predominates in many regions, but ERIC II is the dominant genotype in some countries, so genotype alone does not predict colony-level danger. Removal of larvae before sporulation is also the mechanism by which hygienic behaviour works against the disease, and it is worth holding onto for that reason.

10.3 Reading American Foulbrood in the Field

The signs appear in a sequence that follows the biology, and they are best learned in that order rather than as a list.

The brood pattern goes spotty and irregular. Cells are sealed, unsealed and empty in no order, because the bees uncap and remove some dying larvae and not others, and because the queen re-lays into cleaned cells at a different tempo than the surrounding brood. This is the least specific sign in the chapter and must never be treated as diagnostic on its own.

The cappings change. A dying larva shrinks and dries; the capping over it loses support and sinks. Decomposing tissue gives up moisture, so the capping looks damp, greasy or oily rather than dry and papery, and it darkens well beyond the normal brown. Workers begin chewing into the cell and stop,

leaving small irregular perforations with ragged edges - distinct from the neat circular opening of an emerging bee and from the clean-chewed cells of normal removal.

The colour of the remains progresses. Dull creamy white, then light brown, then the classic coffee-brown, then almost black as the remains dry. If you find an early-stage cell the contents are a semi-fluid brown mass; late-stage cells hold a dry scale.

The remains rope. This is the single most diagnostic field observation available without a laboratory. Insert a small stick - a matchstick, toothpick or grass stem - into a suspect capped cell, stir gently, and withdraw it slowly. Genuine American foulbrood material draws out in a fine, elastic, brown thread that stretches an inch (25 mm) or more before snapping back. The elasticity is the point: what you are pulling is a mass of bacterial cells and degraded larval tissue with the consistency of cooling glue. European foulbrood remains may draw out somewhat - a short thread, usually under about 1.5 cm (5/8 inch) - but the draw is watery and granular and breaks without elasticity, and it does not snap back. Secondary bacteria such as Paenibacillus alvei can make EFB remains ropier, which is one reason a doubtful case goes to the laboratory. Practise on known-healthy larvae so that you know what “no rope” feels like.

The odour. A well-established case carries a distinctive smell variously described as glue-pot, hot animal glue, or a foul sulphurous rot. It is genuinely characteristic once learned and is worth learning. It is also unreliable in early infection and absent in many light cases, which is why authorities are careful to say that odour is not a diagnostic test. Use it as a prompt to look harder, never as a conclusion.

The scale. The endpoint of a dead larva is a hard, dark brown to black, brittle scale lying flat along the lower wall of the cell and extending back toward the base. It is the most important sign for a reason that is purely mechanical: **it cannot be lifted out intact.** During decomposition the remains are semi-liquid and in intimate contact with the cell wall, and as the mass dries it shrinks onto the wax and bonds to it. Try to remove a scale with a probe and it crumbles, leaving fragments glued in place. This is why a beekeeper cannot “clean out” affected comb, why scrubbing and washing accomplish nothing, and why comb from an affected colony has no future. European foulbrood, sacbrood and chalkbrood remains all lift out readily by comparison; adherence is the discriminator.

Two practical aids. Hold the comb at an angle in strong light, with the sun or a bright lamp over your shoulder, and look down into the bases of the cells - scale on a dark cell wall is nearly invisible viewed straight on. And scale fluoresces a greenish-blue under ultraviolet light, which is a genuinely useful screening trick on suspicious dark comb.

The pupal tongue. If the larva survived to the pupal stage before dying, the proboscis of the dead pupa may remain attached to the roof of the cell as the body dries and collapses away from it, leaving a fine thread-like projection extending from the base of the cell across toward the capping. It is uncommon, it is easy to miss, and it is close to pathognomonic. No other brood condition produces it, and finding it in a single cell justifies treating the colony as presumptive American foulbrood pending confirmation.

10.4 Confirming the Diagnosis

10.4.1 Field tests

The **ropiness (matchstick) test** described above is the primary field test and remains the most useful.

The **Holst milk test** is a genuinely elegant field or kitchen-table test that exploits the strong proteolytic enzymes of *P. larvae*. Prepare a suspension of non-fat dried milk or skim milk in water, just cloudy enough to see clearly. Into one tube place a suspect scale or a small amount of suspect larval remains; keep a second tube as an unamended control. Warm both to about 99 degrees F - a pocket, an inside jacket pocket, a warm water bath - and agitate periodically. Within roughly 10 to 20 minutes, a positive sample clears: the bacterial proteases digest the milk protein and the tube turns from cloudy white to a clear brown, while the control remains uniformly cloudy. The test is a quick screening aid, not a confirmation: the USDA handbook calls it not always reliable, so a positive or negative result is followed by laboratory confirmation. It requires viable, active bacteria, so an old, thoroughly dried scale may not respond.

Lateral flow devices for both American and European foulbrood are commercially available and work on the same principle as a home pregnancy test: a diseased larva is crushed in buffer, shaken, and two drops are applied to the device, with a result in about three minutes. They are fast, they require no skill, and they are excellent for screening. Their limitation is that they detect antigen in the sample you gave them. A false negative from a poorly chosen larva, from a sample taken too early, or from a scale rather than fresh remains is entirely possible, and the device detects nothing at all about subclinical spore load. A negative device result on a colony with adherent scale and ropy remains means the sample was bad, not that the colony is clean.

10.4.2 Laboratory confirmation

This is the standard the exam expects. Diagnostic laboratories culture the organism on selective media, examine Gram- and spore-stained smears microscopically, and run conventional or real-time PCR against *P. larvae*-specific primers; biochemical profiling and catalase testing are used in confirmation. Laboratory work also distinguishes clinical disease from spore carriage, which matters for regulatory purposes, and it can characterize the isolate - including antibiotic susceptibility, which a veterinarian will want if any therapeutic route is being considered.

10.4.3 Collecting and submitting a sample

Cut a piece of comb of about 4 square inches (roughly 2 by 2 inches), or whatever size the receiving laboratory specifies, containing as much of the suspect brood as possible. Deliberately include cells with sunken or perforated cappings and any scale you have found - a sample of healthy-looking brood from an affected frame tells the laboratory nothing. **Do not include honey**, which leaks, contaminates the packaging and makes the sample unreadable.

Wrap the comb in paper: newspaper, a paper bag, a paper towel. Place the wrapped sample in a sturdy cardboard box so the comb is not crushed in transit. Enclose a note with your name and address, the date, the apiary location, the hive identification, and a description of what you observed - what fraction of cells were affected, whether the remains roped, whether scale adhered, whether there was odour.

Send it to the designated diagnostic laboratory and notify your state apiary inspector that you have done so.

The packaging error that ruins more samples than anything else is wrapping in plastic, foil or any airtight container. Brood comb carries moisture. Sealed in plastic it sweats, and saprophytic moulds overgrow the sample within a day or two so that nothing can be read and nothing can be cultured cleanly. Paper breathes and the sample arrives dry enough to work with.

One caution about the route. The USDA bee disease diagnostic service, long the national reference point offering free diagnosis to US beekeepers, has had its future called into question: in July 2025 USDA announced that the Beltsville Agricultural Research Center, where the laboratory is housed, will be closed over several years, and in 2026 the future of the service remains unsettled. Several state departments of agriculture and university diagnostic laboratories accept foulbrood samples. The right first call is your state apiary inspector, who knows which laboratory is currently receiving samples and - this matters - whose instructions on sampling and chain of custody take precedence over any general procedure wherever regulatory action may follow. A sample you collected yourself in the wrong way may be diagnostically useful and legally useless.

10.5 Containment: The Interval Between Suspicion and Diagnosis

This is where apiaries are lost, and the exam knows it. Most apiary-wide outbreaks are not created by the pathogen's own dispersal. They are created by the beekeeper in the days between noticing something wrong and finding out what it is.

On finding presumptive American foulbrood, the first actions are:

- **Stop.** No frame, no bee, no box, no tool and no piece of equipment moves out of that colony to any other colony, in this apiary or any other. This includes honey supers, feeders, inner covers and entrance reducers.
- **Close the hive up.** Reduce the entrance to limit robbing, which is the pathogen's own best dispersal route once a colony begins to fail. Do not leave supers or exposed comb where bees can reach them.
- **Disinfect your tools and yourself before touching another colony.** Scorch or bleach-soak the hive tool, wash or change gloves, and consider your suit and veil contaminated if you handled frames.
- **Contact your state apiary inspector** and follow their direction. In most states American foulbrood is reportable, the inspector has statutory authority over the response, and in many jurisdictions destruction is mandated rather than optional.
- **Finish the apiary inspection - last.** Work the remaining colonies to establish how far it has gone, but do that work before you contaminate yourself, or on a separate visit. The standard professional habit is to work known-clean colonies first and suspect colonies last, every time, not just when you are worried.

Three things are commonly proposed and are all wrong. **Do not move a frame from the suspect colony into a strong neighbour** to see whether the disease develops; that is not a diagnostic test, it is a deliberate act of transmission that converts one problem into two. **Do not feed an antibiotic** to see whether things improve; that suppresses the clinical signs while the spore reservoir continues to accumulate, it is unlawful in the United States without veterinary authorization, and it destroys your ability to get a clean diagnosis. **Do not extract the colony's honey** to save the crop; extracting a suspect colony puts spores into your extractor, your tanks, your bottling equipment and eventually your other colonies through returned wet supers.

10.6 Destruction and Decontamination

Once American foulbrood is confirmed, the standard in most jurisdictions is destruction of the bees and the comb, with recovery of the woodenware only if it can be effectively sterilized. The reasoning is now familiar: the reservoir is in the material.

Burning. The classical method is to kill the bees in the evening when all are home, dig a pit, burn frames, comb, bees and any contaminated material in it, and bury the ashes. Burn, do not simply dump - a discarded frame of AFB comb in a hedgerow is an infection source for every colony within flight range, and robbers will find it. Where open burning is restricted, the inspector will direct an alternative, typically deep burial or transport to an approved incinerator.

Scorching woodenware. Boxes, bottom boards and covers can often be saved. The critical detail, and the one the exam tests, is that **the interior must first be scraped free of wax and propolis.** Wax and propolis do not help the wood burn. They insulate it: they melt, they boil off, and while they are doing so the wood surface beneath cannot rise to the temperature that destroys spores. The flame's energy goes into vaporizing the coating rather than heating the wood. Scrape first, then apply a torch until the wood is **uniformly charred** - a genuine dark char across every interior surface including corners, joints and frame rests, not a light browning. If propolis remains, you will see it boil; keep going until it does and until the wood beneath chars. Frames and comb cannot be saved this way and must be destroyed. Scorching cannot be used at all on polystyrene or other plastic equipment, which simply melts; that equipment must be chemically treated or destroyed.

Paraffin dipping. Immersion of boxes in molten paraffin wax at about 160 degrees C - roughly 320 degrees F - for around ten minutes is the established commercial alternative and is used at scale in countries with large migratory industries. It sterilizes and preserves the woodenware in one operation. It is also genuinely dangerous: paraffin's flash point is around 199 degrees C, so the working temperature sits uncomfortably close to ignition, and this is specialist equipment, not a backyard procedure.

Gamma irradiation. Commercial irradiation facilities treat hive equipment with gamma radiation (10 kGy is the accepted minimum for AFB; many US facilities use about 25 kGy), and this is the practical method that sterilizes **both woodenware and drawn comb**. Ethylene oxide fumigation also destroys spores but is rarely available. Where the service is available it is the practical way to save comb from an affected colony, and in some regions it is a routine part of the regulatory response. Availability in the United States is patchy and depends on proximity to a facility willing to take the work.

Chemical disinfection. Sodium hypochlorite is effective: roughly one part household bleach to five parts water, with a full twenty minutes of immersion, kills *P. larvae* spores on hive surfaces. Boiling in caustic soda solution is used commercially. Note what does **not** work, because these are common distractors: acetic acid fumigation (effective against *Vairimorpha* (*Nosema*) and wax moth, useless against AFB spores), washing soda solutions, ordinary detergents, freezing, a season standing empty, and sunlight.

Honey and wax. Honey from an affected colony must not be fed to bees, ever, including as a treat to another colony or in an open feeder. Wax rendered from affected comb carries spores; commercial rendering temperatures do not reliably sterilize it, which is one of several reasons that foundation should be sourced commercially rather than made from comb of unknown origin, and one reason that some countries require irradiation of imported beeswax.

10.7 Antibiotics: What They Do, What They Do Not Do, and the Law Since 2017

10.7.1 The substantive point first

Antibiotics act on vegetative bacteria. They do nothing whatever to spores. Feed oxytetracycline to a colony with clinical American foulbrood and the vegetative rods in the gut of newly infected larvae are suppressed; larvae that would have died survive; the brood pattern tightens up; the ropy remains stop appearing. The colony looks cured.

Nothing has been cured. The scales in the comb still hold their billion spores each. The stored honey still holds spores. The woodenware still holds spores. The colony is still fully infectious to every colony the beekeeper touches with the same hive tool and to every robber that visits. What the antibiotic has done is remove the beekeeper's ability to see the problem while leaving the problem entirely intact. This is the meaning of the statement that **antibiotics mask American foulbrood rather than curing it**, and it is why prophylactic feeding was, in hindsight, a genuinely harmful practice: it concealed disease in medicated colonies and guaranteed a spectacular outbreak whenever medication stopped. It also turned the treated colony into a long-term reservoir seeding its neighbours.

10.7.2 The regulatory position

Since **1 January 2017**, under FDA Guidance for Industry 213 and the Veterinary Feed Directive rule, the medically important antimicrobials used in honey bees require veterinary oversight. In-feed products such as oxytetracycline for bees require a **Veterinary Feed Directive**; water-soluble products such as tylosin and lincomycin require a **prescription**. Over-the-counter purchase is gone, and routine prophylactic feeding - historically a spring-and-fall ritual in many operations - is no longer lawful.

The three compounds with US approvals for honey bees are oxytetracycline (the long-standing product), **tylosin, approved in October 2005**, and **lincomycin, approved in March 2012**. All three are now VFD or prescription products. The label pattern for the oxytetracycline product is instructive: three applications at four- to five-day intervals, as a dust, in syrup or in an extender patty, fed in spring or fall, with the requirement to remove medication **at least six weeks before the main honey flow begins** so that residues do not enter the crop. Extra-label use is prohibited.

The change is as much practical as legal. A beekeeper who wants an antibiotic now needs a veterinarian, and a veterinarian needs a valid veterinarian-client-patient relationship and a diagnosis. That requirement pushes the whole system toward laboratory confirmation rather than treating on suspicion, which is a real improvement in how the disease is handled. The number of veterinarians comfortable with honey bees is small but has grown substantially since 2017, and several state veterinary associations now maintain lists.

10.7.3 Resistance

Oxytetracycline resistance in *P. larvae* was documented in Argentina in the 1990s and verified in the United States around the turn of the century (Miyagi and colleagues, 2000). The resistance determinants are tetracycline-resistance genes carried on mobile elements, and there is good evidence that they arrived in *P. larvae* from the wider bacterial community rather than evolving in place - long-term antibiotic feeding has been shown to accumulate resistance genes in the honey bee gut microbiota generally, which is the reservoir the pathogen draws from. Oxytetracycline-resistant strains continue to be detected in commercial operations; a 2023 Canadian survey using pooled honey sampling found them in commercial beekeeping operations at a rate that surprised the investigators. Resistance is exactly what decades of sub-therapeutic prophylactic feeding would be predicted to produce.

10.7.4 Where antibiotics do have a defensible role

European foulbrood is the honest case. Because *M. plutonius* forms no durable spore, suppressing the vegetative organism actually does something useful, and antibiotics have historically been part of the response in commercial settings, particularly where colonies must perform in pollination within a few weeks. A 2026 Canadian trial (Jose and colleagues, Journal of Insect Science) comparing oxytetracycline, tylosin and lincomycin in 48 clinically affected colonies found all three produced significant gains in colony strength and substantial reductions in *M. plutonius* load in adult bees. Two findings from that trial deserve attention. First, the sham-treated control colonies also gained some strength over the same period, although, unlike the treated groups, not significantly - spontaneous improvement does occur in European foulbrood, so any uncontrolled observation that “the antibiotic worked” deserves caution. Second, the treatments did not correspondingly clear *M. plutonius* from larvae, so the reservoir in the colony persisted and recurrence risk with it. Antibiotics buy a colony time in European foulbrood; they do not resolve the underlying situation, which is usually nutritional and managerial.

10.8 European Foulbrood: Starvation by Competition

Melissococcus plutonius is a Gram-positive, lanceolate coccus about 0.5 by 1.0 micrometres, which requires reduced oxygen to grow and which **forms no true durable spore**. That last fact is the axis on which the whole disease turns.

10.8.1 The mechanism

The larva ingests the bacterium in its food. *M. plutonius* multiplies massively in the midgut lumen and competes with the larva for the nutrients passing through it. The larva is not primarily invaded; starvation is the accepted core of the disease. Strains differ greatly in virulence, and putative toxins and other virulence factors are still being studied, so the full mechanism is not settled. Death follows in

larvae typically four to five days old, which is **one to two days before the cell would have been capped**, though a minority die shortly after capping - enough that a few sunken, perforated cappings in an otherwise open-cell picture do not exclude European foulbrood.

That mechanism explains the disease's entire epidemiology. Anything that reduces the nutrient supply to larvae, or that increases the number of larvae competing for a fixed supply, tips the balance toward the bacterium. Hence the classic associations: rapid spring build-up, when brood numbers outrun the forager force; poor or interrupted forage; cold or wet weather that keeps foragers home; colonies that have been pushed hard for early pollination; colonies moved into crops with thin or nutritionally poor pollen. Highbush blueberry pollination is the textbook trigger in North America and has been studied directly for exactly this reason. Colonies frequently improve on their own when the flow arrives - which is real, and which is also the most dangerous fact about the disease, because it teaches beekeepers that whatever they happened to do worked.

10.8.2 The field picture

Larvae die uncapped in open cells, where you can see them plainly. They lose the neat C-shaped coil of a healthy larva and appear **twisted, displaced, or collapsed in abnormal positions** - across the cell, up the wall, slumped rather than curled. Colour runs off-white to yellow, then tan, then brown. The consistency is watery to pasty, sometimes described as melted. The tracheal system is often visible as a whitish tracery through the translucent body of a recently dead larva, which is a good confirmatory detail. Remains do not rope elastically. Dried remains are rubbery to loosely dry, brown, often lying twisted rather than neatly along the lower wall, and - critically - **they lift out of the cell in one piece.**

Odour is variable and comes largely from secondary invaders rather than from *M. plutonius* itself. The dead larva is a rich substrate, and a predictable succession of bacteria moves in: *Paenibacillus alvei*, itself a spore-former, which produces the stale or sour smell most beekeepers associate with the disease; *Enterococcus faecalis*, which resembles *M. plutonius* microscopically but is culturally distinct and contributes a sour note; *Achromobacter eurydice*; *Brevibacillus laterosporus*. This is why descriptions of European foulbrood odour vary from "no smell" through "sour" to "foul" - you are smelling whichever secondary organisms happened to arrive, in whatever proportion. Note the trap in *P. alvei*: it does form spores, and a beekeeper told that "European foulbrood organisms form no spores" who then reads about *P. alvei* may conclude the teaching was wrong. The causative organism forms none; a common secondary invader does, and it is not what causes the disease.

10.8.3 Why no spore changes the management entirely

M. plutonius persists in the colony by mechanical contamination - bacteria on comb surfaces, in stored food, in the guts of adult bees which act as carriers without being harmed. That contamination is durable enough that **recurrence in subsequent seasons is common**, and honest guidance says so. But it is not the geological persistence of a bacterial endospore in dry scale, and it is reachable by ordinary management. So the legitimate options for European foulbrood - every one of which is illegitimate for American foulbrood - are:

Improve nutrition. Feed syrup and a pollen substitute if forage is short. Because the mechanism is competition for larval food, improving the food supply directly attacks the mechanism. This is the intervention most often skipped and most often decisive.

Requeen, for the brood break as much as the genetics. A break in laying empties the brood nest, removes the susceptible stage for a period, gives house bees time to clean cells, and interrupts the transmission cycle. Requeening with hygienic stock adds removal of infected larvae before they can contaminate further.

Replace comb. Culling the most heavily affected brood comb removes a large fraction of the reservoir at modest cost.

Shook swarm in the heavier cases, discussed below.

Reduce the stress that produced it. If the colony is in a crop that predictably produces the disease, the answer may be a different rotation, better supplemental feeding during that crop, or stronger colonies going in.

10.8.4 The shook swarm

A shook swarm transfers all the adult bees from the affected colony onto fresh foundation in clean equipment; the old comb, brood and stores are destroyed. It removes the pathogen reservoir held in comb and brood in a single operation, and it is the accepted structural response to European foulbrood in strong colonies and to heavy comb contamination generally.

The classic UK field comparison (Waite, Brown, Thompson and Bew, *Apidologie* 34: 569-575, 2003) is the number to know. Shook swarm combined with oxytetracycline and oxytetracycline alone performed almost identically within the season, at about 95 and 96 percent apparent success. The difference showed up the following year: **recurrence was 4.8 percent in the shook-swarm-plus-oxytetracycline group against 21.1 percent in the antibiotic-only group.** The trial was small (25 colonies shook-swarmed and treated, 21 treated with oxytetracycline alone) and the difference was suggestive rather than conclusive, significant only at the 10 percent level, but it fits the argument in one line - the antibiotic addressed the bacteria, the shook swarm addressed the reservoir.

The manipulation is expensive to the colony. It costs every frame of brood and every pound of stores, so it demands preconditions: a genuinely strong colony with enough adult bees to draw foundation and cover a new nest, warm weather, and either a reliable flow or committed feeding. Shaking a marginal colony in cool weather kills it. It is a substantial intervention, not a routine spring manipulation.

And it is **not** an accepted substitute for destruction in confirmed American foulbrood. The reasoning follows from the spore biology: adult bees shaken from an AFB colony carry spores in their guts, on their bodies and in whatever honey they carry with them, and they will contaminate the fresh comb they draw. Some jurisdictions have historically permitted shook swarms for AFB under strict inspector supervision, with a starvation period in a confinement box, double shaking and burning of the interim comb. Absent that specific regulatory framework and supervision, it is not an option a beekeeper may choose, and in most US states destruction is legally mandated.

10.9 Chalkbrood

Ascosphaera apis is a fungus, and the clinical picture is unmistakable once seen: hard, chalky, mummified larvae, white through grey to black, filling the cells, appearing on the bottom board and scattered in front of the entrance where the bees have dragged them out. Mummies at the entrance are often the first sign a beekeeper notices, before any brood inspection is done.

10.9.1 The mechanism, which explains the management

Young larvae ingest spores in their food. Germination requires elevated carbon dioxide, which the larval gut conveniently supplies, so the spore activates after ingestion rather than in the open hive. Hyphae grow through the gut wall and out through the larval body - characteristically breaking out at the posterior end and leaving the head relatively intact, which is why many mummies show a distinct darker "head" - and mycelium fills the cell, swelling and then drying the larva into the chalk-like mass that gives the disease its name. Death generally occurs after capping.

The temperature relationship is the key to everything else. *A. apis* grows best at around **30 degrees C (86 degrees F)** and is markedly inhibited at **35 degrees C (95 degrees F)**, which is precisely the temperature a healthy colony maintains in the brood nest. A colony that holds brood nest temperature is holding the fungus below its optimum. Anything that lets brood temperature drop toward 30 degrees C - a weak colony, a brood nest split across boxes, a cold snap during rapid spring expansion, a long inspection in cool weather, a damp shaded site, poor ventilation - creates the fungus's preferred conditions. **Chalkbrood is not principally a pathogen problem; it is a thermoregulation problem with a fungus attached.** The spores are ubiquitous. The conditions are what vary.

10.9.2 White versus black mummies

A. apis is heterothallic: it has two mating types, conventionally plus and minus, and sexual reproduction with formation of spore cysts occurs only where mycelia of opposite mating types meet. A mummy colonized by a single mating type stays white or greyish and is essentially a lump of sterile mycelium. A mummy in which both mating types are present develops spore cysts and turns grey-green to black. **The colour therefore tells you the infective spore load.** White mummies are largely a cosmetic nuisance; dark mummies are the colony's own spore factory and are the ones to get out of the hive. Spores remain infective in comb and equipment for around fifteen years, so the reservoir is durable in ordinary beekeeping terms even though nothing like AFB's decades.

10.9.3 Management of a persistent case

Consider a colony in a shaded, poorly drained site that goes down with chalkbrood every spring. The response is entirely about conditions and stock, and there is a specific reason that no chemical treatment appears in it: **nothing is registered for chalkbrood in the United States, and no fungicide has proven both effective and safe in a food-producing hive.**

Correct the site. Move the hives to a spot that gets morning sun and dries early; the point of morning sun is that it warms the cluster and dries the nest at the coldest hour rather than baking the colony at midday. Get the hives off the ground onto stands. Improve drainage, or move off the wet ground

entirely. Tilt the hive slightly forward so condensation runs out rather than dripping onto the cluster. Ensure adequate ventilation, with attention to the top, where moisture condenses.

Strengthen the colony so it can hold 95 degrees F across the brood it is trying to rear. Do not run a weak colony with more brood area than its bees can cover. Avoid chilling brood yourself: keep cool-weather inspections short, do not leave the brood nest broken open, and do not split a brood nest across two boxes in cool weather.

Requeen with hygienic stock. This is the intervention with the strongest evidence, and the mechanism is direct - hygienic workers detect and remove infected larvae before the mycelium reaches the point of producing spore cysts, so incidence falls and the reservoir stops growing.

Replace heavily affected comb, which cuts the spore load. Feed if nutrition is marginal. And be patient: with the conditions corrected, chalkbrood typically fades over a season or two.

10.10 Stonebrood

Stonebrood is uncommon, and it is in this chapter for two reasons: it is a fungal brood disease that belongs in the differential, and it is the one brood disease that carries a genuine **human health caution**.

It is caused by *Aspergillus* species, principally *A. flavus* and *A. fumigatus*, with *A. niger* also implicated. Affected larvae and pupae are overgrown by mycelium and harden into mummies that are unusually hard - the name comes from how stone-like they feel compared with the friable chalkbrood mummy. When sporulating, the mummies are covered with a powdery growth that is characteristically **green to yellow-green** (*A. flavus*) or grey-green (*A. fumigatus*), which is the distinguishing feature: chalkbrood mummies run white to grey-black and never green. A collar of fungal growth often forms near the head. Unlike the other diseases in this chapter, *Aspergillus* also affects **adult bees**, which become sluggish, are removed from the colony by nestmates, and mummify outside.

The caution is real. *A. fumigatus* and *A. flavus* are opportunistic human pathogens - the agents of aspergillosis, which is a serious and sometimes fatal invasive lung disease in immunocompromised people - and *A. flavus* produces aflatoxins, which are potent mycotoxins. Handling sporulating comb generates aerosolized spores in quantity. **Wear gloves and respiratory protection** when handling suspected stonebrood; a fitted N95 or better is the appropriate level. Do not bang frames, do not brush dry sporulating mummies, and bag affected comb before moving it rather than carrying it in the open. Anyone immunocompromised, on corticosteroids, or with existing lung disease should not handle it at all.

The distractors the exam builds here are worth naming. Stonebrood mummies are not dangerous because they are sharp. Stonebrood is not notifiable. It is not notably contagious between apiaries; it is an opportunistic infection associated with damp comb and stressed colonies, and management is the same environmental correction as for chalkbrood, with destruction of affected comb.

10.11 Sacbrood in the Differential

Sacbrood is a viral disease - sacbrood virus, an iflavirus - and it belongs in a bacterial-and-fungal chapter for one reason: it is the condition most often confused with early foulbrood, and a candidate who cannot exclude it cannot reason through a brood differential.

The affected larva takes up virus in its food, dies **about two days after its cell is capped**, and fails at the final larval-to-pupal moult. The fluid that should be resorbed during ecdysis accumulates between the old cuticle and the body, so the dead larva becomes a fluid-filled bag. Lift it with forceps and it comes out **intact, as a sac**, holding a granular, greyish, almost clear fluid. Nothing else in the differential does this, and it is worth the trouble of trying on a suspect larva.

The larva lies stretched on its back along the lower wall of the cell, head toward the capping. Colour progresses white to grey or pale yellow, then brown, then nearly black, darkening from the head first. The dried remains curl upward at the head end into a distinctive shape - the gondola or Chinese-slipper scale - and, decisively, **the scale lifts out of the cell easily**. Cappings are perforated or removed. There is no characteristic odour, and the remains do not rope.

Sacbrood is most common in spring, when brood rearing is heaviest, and it is largely self-limiting. Infected nurse bees are the main transmission route: the virus replicates in their hypopharyngeal glands and enters brood food. Infected workers stop nursing early and shift to foraging, which is a behavioural quarantine that limits the outbreak. Management is comb replacement, requeening if a substantial fraction of brood is affected, and attention to general colony strength and nutrition. There is no treatment, and none is needed in most cases.

10.12 Chilled Brood and the Argument from Pattern

This is the reversal the exam tests directly, so hold it carefully.

Chilling kills whatever is in the chilled zone, regardless of stage or age. Cold does not select; it does not care whether a cell holds an egg, a two-day larva or a pupa a day from emergence. Every occupant of the cooled area dies, and the mortality stops sharply at the edge of the zone the cluster could still cover. The result is a **bounded, contiguous patch of dead brood** in which all stages are represented - typically at the periphery of the brood nest, on outside frames, along the top bars of a lower box when the cluster moved up, or across a face of comb that was left exposed.

Infection kills scattered individuals according to susceptibility and stage. Whether a particular larva dies depends on whether it received an infective dose during its window of susceptibility, on genetics, on which nurse bee fed it, and on whether the bees removed it in time. That is a probabilistic process, so affected cells appear scattered among healthy neighbours across the brood area, and the affected cells cluster by developmental stage - the stage the pathogen kills - rather than by location.

Bounded and indiscriminate means environment. Scattered and selective means pathogen. Reading it backwards sends a beekeeper hunting for a pathogen after their own cool-weather inspection caused the loss, which is the specific mistake the item is built to catch.

The appearance of chilled brood supports the reading. Dead larvae and pupae turn grey to dark brown or black, they are not ropy, they lift out easily, and the bees drag them out in quantity - a sudden litter of discoloured pupae on the landing board after a cold snap is the classic presentation. Causes are almost always managerial: an inspection that kept the brood nest open too long in cool weather, a split made too small or too early, a brood nest broken across boxes so the cluster cannot cover both, supering ahead of the colony's ability to hold heat, a colony left short of bees after a swarm, or a pesticide kill that removed the adult population that was keeping the brood warm.

10.13 The Spotty Brood Pattern Is a Sign, Not a Diagnosis

A spotty pattern is the most over-interpreted observation in beekeeping. It is a signal that something reduced brood viability or disrupted laying, and essentially every problem in this book can produce it. The differential:

- **American foulbrood** - scattered post-capping death with sunken perforated cappings.
- **European foulbrood** - scattered pre-capping death with twisted larvae in open cells.
- **Sacbrood** - scattered post-capping death with sac-like larvae.
- **Chalkbrood** - mummies in cells, empty cells where they have been removed.
- **Chilled brood** - the bounded patch described above, which is not truly spotty but is often described as such.
- **Heavy Varroa infestation with the associated virus complex** - brood death, removal of infested pupae, and the deformed-wing adults that go with it. Take a mite count as part of any brood-pattern investigation; this is the single most common actual answer.
- **A failing or poorly mated queen** - erratic laying, skipped cells, multiple eggs, drone brood in worker cells.
- **Laying workers** - multiple eggs per cell, eggs on cell walls, scattered domed drone cappings in worker comb.
- **Inbreeding and diploid drone removal** - the queen lays a full pattern, nurse bees eat the homozygous diploid drone larvae within hours of hatching, and the beekeeper sees empty cells scattered through good brood with no dead larvae at all. The distinguishing feature is the absence of any remains.
- **A pollen- or honey-bound brood nest** - cells visibly full of beebread or nectar, restricting where the queen can lay.
- **Plant toxin disorders** - in the southeastern US, purple brood from titi (*Cyrilla racemiflora*) during its bloom in the coastal plain and river swamp country, where larvae turn blue-purple and die; buckeye poisoning in the piedmont and mountains. The tell is that these appear suddenly, hit every colony in the affected area at once, and resolve when the bloom ends.

Why the list matters: a beekeeper who sees a spotty pattern and automatically requeens may replace a perfectly good queen while leaving a mite infestation or a foulbrood infection entirely untouched - and,

worse, may introduce a new queen into a colony whose actual problem will kill her too. The professional habit is to examine the cells themselves before forming a view: capping appearance, position and appearance of any dead brood, a ropiness test on discoloured capped larvae, adherence of any scale, a mite count, and the colony's own history and season.

10.13.1 The test frame, used properly

A **test frame** is a frame of eggs and very young larvae taken from a known-healthy colony and inserted into the brood nest of a colony whose problem you are trying to identify. It is a powerful tool because it separates two things that look identical: a queen problem and an environment problem.

If the recipient colony rears that brood to a good solid pattern, the cells and the nurse bees are fine and the fault lay with the queen or her mating. If the introduced brood dies in the same way the colony's own brood was dying, the problem is in the colony - disease, comb contamination, pesticide, or chilling - and requeening would have been useless. As a secondary use, drawing emergency queen cells on an inserted test frame is the standard confirmation that a colony is genuinely queenless.

The absolute precondition: **never use a test frame when American foulbrood cannot be excluded.** You would be moving comb from a healthy colony into a suspect one, which is exactly the transmission event the containment rule forbids, and you cannot get the frame back. Exclude AFB first. Test frames are for distinguishing queen failure from a colony-level problem in colonies where the brood signs do not suggest foulbrood, and for that they are excellent.

10.14 The Differential Table

Feature	American foulbrood	European foulbrood	Sacbrood	Chalkbrood	Chilled brood
Agent	*Paenibacillus larvae* (bacterium, spore-forming)	*Melissococcus plutonius* (bacterium, no spores)	Sacbrood virus (iflavirus)	*Ascosphaera apis* (fungus, spores)	None - environment
Age at death	After capping	Mostly before capping (4-5 days), some after	About 2 days after capping	After capping	Any stage
Position in cell	Stretched flat along lower wall	Twisted, displaced, collapsed	Stretched on back, head to capping	Fills the cell	As they lay
Colour	White, tan, coffee-brown, black	Off-white, yellow, brown	White, grey, brown, black from head	White, grey, black, or a marked head	Grey to black
Consistency	Ropes elastically 1 inch or more	Watery to pasty; no elastic rope	Fluid-filled intact sac	Hard, chalky	Soft then dry; no rope
Scale removable?	**No - adheres, crumbles**	Yes, lifts out	Yes, gondola-shaped	Yes, may rattle	Yes

Feature	American foulbrood	European foulbrood	Sacbrood	Chalkbrood	Chilled brood
Cappings	Sunken, dark, greasy, irregularly perforated	Mostly open cells; some sunken	Perforated or removed	Perforated or removed	Normal over dead brood
Odour	Glue-pot / foul (unreliable early)	Sour or stale, from secondary invaders	None	None	None
Pattern	Scattered by susceptibility	Scattered, worse in build-up	Scattered, spring	Scattered; mummies at entrance	**Bounded contiguous patch**
Pathognomonic sign	Adherent scale; pupal tongue	-	Intact fluid sac	Chalk mummy	Sharp boundary, all stages
Management	Destruction / irradiation; regulated	Nutrition, requeen, comb, shook swarm	Comb replacement, requeen	Site, strength, hygienic stock	Fix the management

10.15 The Decision Sequence

On finding an abnormal brood pattern, work in this order.

First, examine the cells themselves, in good light. Capping appearance - sunken, perforated, greasy, darkened. The position and appearance of dead brood. Odour, noted but not relied on. A ropiness test on discoloured capped larvae. The adherence and shape of any scale, with the comb tilted to the light. Whether any larva lifts out as an intact sac.

Second, consider and systematically exclude the alternatives. Run the full list: American foulbrood, European foulbrood, sacbrood, chalkbrood, stonebrood, chilled brood, plant toxin disorders, failing queen, laying workers, inbreeding, and heavy Varroa infestation. Take a mite count as part of this, not as an afterthought - parasitic mite syndrome accounts for far more abnormal brood in the field than all the foulbroods put together.

Third, weigh colony history, season and management. Was this colony split three weeks ago? Requeened? Moved into blueberries? Left with brood across two boxes during a cold snap? Bought as used equipment? Is every colony in the yard showing it, or just this one? Uniform across the yard points to environment, weather or forage; one colony in ten points to the colony.

Fourth, if American foulbrood cannot be excluded, get laboratory confirmation through the state apiary inspector. Not a field opinion, not a second opinion from the club, not a wait-and-see. Confirmation.

And throughout: nothing moves. No frame, no bee, no tool, no box leaves the suspect colony for any other until the diagnosis is settled. That rule is the substantive answer to the whole question, because the interval between suspicion and diagnosis is when apiary-wide outbreaks are created.

The justification for this structure is the asymmetry of consequences. Field discrimination between the foulbroods is good but not perfect - ropiness, scale adherence and the pupal tongue are strong signs, but light early AFB with few affected cells and no odour is genuinely hard, and secondary invaders can make EFB remains smell and look worse than they are. When one branch of a decision costs a lab fee and a few days and the other branch costs an apiary, you do not optimize for accuracy. You optimize for the cost of being wrong.

10.16 Biosecurity: Comb, Equipment and the Beekeeper as Vector

10.16.1 Used equipment is the highest-risk purchase in beekeeping

Acquiring used equipment, particularly drawn comb of unknown history, is the classic route by which a beekeeper destroys their own apiary. Drawn comb is genuinely valuable - a package on drawn comb outperforms one on foundation by a wide margin - and the price of used comb bears no relation to what it can cost you. Spores in that comb are viable for decades; the seller may be entirely honest and simply not know; and there is no way to look at comb and be certain.

Reasonable precautions: establish the seller's disease history and whether their colonies have ever been inspected; inspect every frame carefully in good light for scale, perforated cappings and the fluorescence of AFB scale under UV; strongly prefer equipment without comb, since woodenware can be sterilized and comb cannot; scorch or otherwise sterilize woodenware before use regardless of how clean it looks; and check whether your state requires inspection or certification for the transfer of used equipment, which many do. When comb comes with a story about a "deadout from mites," ask what the brood looked like.

10.16.2 Moving brood between colonies is an epidemiological event

Equalizing an apiary by moving frames of brood from strong colonies to weak ones is standard practice and is a genuine transmission mechanism. What moves with that frame is whatever the donor carries: *P. larvae* spores, *M. plutonius*, chalkbrood spores, *Vairimorpha* (*Nosema*) spores, the virus complex, and Varroa in the sealed brood. Blind equalization can distribute a disease through an entire apiary in a single afternoon, and the beekeeper will not learn about it for weeks.

To do it responsibly: **first determine why the recipient is weak.** A frame of brood does not fix a failing queen or a mite load of twelve per hundred; it feeds the problem. Take brood only from colonies you have inspected carefully and believe healthy, not simply from the biggest colony. Do not weaken the donor below what it needs for its own season. Do not move comb between apiaries, and never from colonies whose history you do not know. Clean the hive tool between colonies, and work any suspect colony last. The general principle is worth stating flatly: **any manipulation that moves comb between colonies is an epidemiological event and should be preceded by a health assessment.**

10.16.3 Comb rotation

Comb rotation is the systematic culling and replacement of the oldest brood combs. The common target is about **20 percent of brood comb per year**, so that no comb stays in service more than about five years. Three reasons, all substantive:

Residues. Beeswax is lipophilic and accumulates the lipophilic pesticides and miticides the colony encounters - fluvalinate, coumaphos, amitraz breakdown products, and a long tail of agricultural compounds. Large surveys of North American apiaries have found a startling burden of residues in wax, and those residues persist for years. Worse, culled wax is rendered and recycled into commercial foundation, so the contamination circulates back into hives.

Pathogens. Old comb accumulates chalkbrood spores, *Nosema*, virus and bacterial contamination. Culling old comb removes reservoir, which is why comb replacement appears in the management of European foulbrood, chalkbrood and sacbrood alike.

Physical deterioration. Every bee reared in a cell leaves a cocoon behind. Cells narrow measurably over years, comb darkens until you cannot see eggs or read the condition of larvae, and the structure becomes brittle and prone to breaking out of the frame. Dark comb is also far more attractive to wax moth, which are drawn to the protein in accumulated cocoons rather than to the wax itself.

Implementation is trivial: mark each frame with the year it was drawn, move the oldest frames to the outside of the brood box during the season so the queen abandons them, and pull them at the end of it. In the southeastern US, render culled dark comb promptly rather than stacking it in the shed - stored dark comb in a warm humid climate is prime substrate for wax moth and small hive beetle, and you will lose it anyway.

10.17 Hygienic Behavior as Brood Disease Resistance

Hygienic behavior is the detection and removal of diseased or dead brood from sealed cells by workers. The mechanism that makes it a disease-resistance trait is specific and is what the exam wants: **workers remove the affected larva before the pathogen completes its development and produces its infective stage.**

For American foulbrood, that means uncapping and removing the larva while the bacterium is still in the vegetative phase, before it has sporulated inside the corpse. Vegetative *P. larvae* removed from the hive is a dead end - it is not infective and does not survive. If instead the larva is left to dry into a scale, the colony has manufactured a billion spores. The behaviour does not make the individual larva survive; it interrupts the pathogen's life cycle at the step that matters, which is why hygienic stock shows real reductions in American foulbrood incidence.

For chalkbrood the logic is identical: remove the infected larva before the mycelium produces spore cysts, and the spore load in the colony stops growing. Hygienic stock's performance against chalkbrood is, if anything, better documented than against AFB.

Two honest qualifications. **It is reduction, not immunity.** A hygienic colony given a heavy enough spore dose will develop clinical disease; the trait shifts the probability, it does not eliminate the disease.

Hygienic stock complements inspection, comb management and biosecurity rather than replacing any of them, and a beekeeper who stops inspecting because the stock is hygienic has made the trait worse than useless. And **hygienic behaviour tracks brood diseases far better than it tracks Varroa**, because detecting a dead or diseased larva is a different sensory problem from detecting a living mite reproducing under an intact capping over a healthy pupa - that is Varroa-sensitive hygiene, a related but distinct and separately selected trait.

The standard assessment is the **freeze-killed brood assay**: kill a measured patch of sealed brood with liquid nitrogen or by cutting and freezing a comb section, return it, and score the percentage removed at 24 hours. About 95 percent or more removal within 24 hours, on two consecutive tests, is the conventional definition of a hygienic colony (the original protocol read at 48 hours). It is entirely within reach of a sideline beekeeper, and two tests are required because a single score varies with colony strength, season and forage.

10.18 Numbers to Know Cold

Figure	Value	Why it is that value
AFB infective dose, young larvae	Fewer than 10 spores (LD50 about 8-9)	The bacterium crosses the midgut of a larva whose peritrophic membrane is not yet formed; almost no barrier exists, so a trivial dose suffices
AFB larval susceptibility window	Roughly the first 24-48 hours after hatching; no infection after about 53 hours	Maturation of the peritrophic membrane plus the shift from pure glandular food to a diluted diet closes the route
Spores in one infected larva/scale	On the order of 1 billion; figures to about 2.5 billion cited	The entire larval body is converted to bacterial biomass, then sporulates
AFB spore viability	35 years or more in scale; over 70 years for purified spores	Bacterial endospores are metabolically inert and resist desiccation, heat and chemicals
AFB ropiness test positive	Elastic brown thread of 1 inch (25 mm) or more	The mass is bacterial cells plus degraded tissue with the consistency of animal glue; EFB may draw a short thread, usually under about 1.5 cm, but without elasticity
ERIC I time to larval death	About 12 days	Slow kill means death well after capping and full sporulation before removal - the textbook ropy-remains picture
ERIC II time to larval death	About 7 days	Fast kill allows hygienic removal before sporulation - can make outbreaks less conspicuous, though genotype alone does not predict colony-level danger

Figure	Value	Why it is that value
AFB comb sample size	About 4 square inches (check lab), no honey, wrapped in paper	Big enough to include affected cells and scale; paper breathes so the sample does not mould in transit
Gamma irradiation dose	10 kGy minimum for AFB (about 25 kGy commonly used)	The practical method that sterilizes drawn comb as well as woodenware
Paraffin dipping	About 160 degrees C (320 degrees F) for 10 minutes	Sterilizes and preserves; flash point of paraffin is near 199 degrees C, so the margin is thin
Bleach disinfection	1 part household bleach to 5 parts water, 20 minutes immersion	Hypochlorite destroys spores given adequate contact time; brief wiping does not
Scorching standard	Uniform char, after scraping off wax and propolis	Wax and propolis insulate the wood and absorb the heat; light browning does not reach spore-killing temperature
EFB larval age at death	4-5 days old, typically 1-2 days before capping	The larva starves once bacterial competition in the midgut exceeds its nutrient intake
EFB recurrence, shook swarm plus oxytetracycline (Waite et al. 2003)	4.8 percent for shook swarm plus oxytetracycline, vs 21.1 percent for oxytetracycline alone (suggestive, significant only at the 10 percent level)	Removing the comb reservoir addresses the source; the antibiotic addresses only the bacteria present
Brood nest temperature	93-95 degrees F (about 34-35 degrees C)	The physiological optimum for pupal development, and above the chalkbrood fungus's growth optimum
Ascosphaera apis growth optimum	About 30 degrees C (86 degrees F); inhibited at 35 degrees C	Healthy brood nest temperature suppresses the fungus; any chilling toward 30 degrees C favours it
Chalkbrood spore viability	About 15 years in comb and equipment	Durable but not in the AFB class, so comb culling meaningfully reduces the reservoir
Sacbrood time of death	About 2 days after capping	The larva fails the final moult and ecdysial fluid accumulates, forming the sac
Oxytetracycline label pattern	3 applications at 4-5 day intervals; remove at least 6 weeks before the main flow	Covers successive brood cohorts; the withdrawal protects the crop from residues
Veterinary oversight for bee antibiotics	Required since 1 January 2017	FDA GFI 213 and the VFD rule ended over-the-counter and prophylactic use of medically important antimicrobials

Figure	Value	Why it is that value
Tylosin US approval	October 2005	Added after oxytetracycline resistance was verified in US *P. larvae*
Lincomycin US approval	March 2012	Third approved compound, also now prescription-only
Comb rotation target	About 20 percent of brood comb per year; nothing older than about 5 years	Limits residue accumulation, pathogen reservoir and cell narrowing from accumulated cocoons
Hygienic colony standard	About 95 percent or more removal of freeze-killed brood within 24 hours, on two tests	Two tests because a single score varies with strength, forage and season

10.19 Common Misconceptions

Misconception: American and European foulbrood are two versions of the same problem, so they are managed the same way. **Correction:** They share a name and nothing else that matters. *P. larvae* forms an endospore that survives 35 years or more in comb and wood; *M. plutonius* forms no spore at all. That single difference means AFB management must target the material - destruction, irradiation, sterilization - while EFB management can legitimately target the colony through nutrition, a brood break, comb replacement and shook swarm. The names are a historical accident of where each was first described.

Misconception: Antibiotics cure American foulbrood; a treated colony and its equipment can go back into normal service. **Correction:** Antibiotics act on vegetative bacteria and have no effect whatever on spores. A treated colony stops showing signs while its comb still holds scales containing a billion spores each. It remains fully infectious to every colony the beekeeper touches and to every robber that visits. The treatment removes the symptom and leaves the reservoir, which is why prophylactic feeding was actively harmful and why destruction or irradiation remains the disposal standard.

Misconception: If the colony looks strong at the entrance, it does not have foulbrood. **Correction:** Adults are not susceptible to *P. larvae*. Only larvae in their first day or two are. An infected colony forages normally and looks normal from outside while brood mortality accumulates in sealed cells; the adult population falls only much later, when replacement fails. Entrance assessment is worthless for this disease, which is precisely why cell-by-cell brood inspection in good light is a biosecurity practice.

Misconception: Contaminated equipment becomes safe after a season standing empty, or after a hard winter. **Correction:** Endospores are metabolically inert. They are unaffected by freezing, drying, sunlight, ordinary detergents, acetic acid fumigation or the passage of time on any scale a beekeeper operates on. Purified spores have been recovered viable after seventy years. Only heat sufficient to char the wood, hypochlorite with real contact time, molten paraffin, gamma irradiation or fire destroys them.

Misconception: A quick pass of the torch over a hive body sterilizes it. **Correction:** Wax and propolis on the interior surfaces insulate the wood and consume the flame's energy in melting and vaporizing rather than heating. The box must be scraped clean first, then heated until the wood itself is **uniformly charred**

into every corner and joint. Light browning is not the standard. And scorching is not an option for polystyrene equipment, which melts.

Misconception: A shook swarm can save the bees from a confirmed American foulbrood colony. **Correction:** Adult bees shaken out of an AFB colony carry spores in their guts, on their bodies and in the honey they bring with them, and will contaminate the fresh comb they draw. Some jurisdictions have permitted supervised double-shook procedures with confinement and starvation periods; absent that specific regulatory framework, it is not a beekeeper's option, and in most US states destruction is mandated. Shook swarm is a legitimate tool for European foulbrood, not a substitute for AFB destruction.

Misconception: Chilled brood shows up as scattered dead larvae through the brood nest. **Correction:** The pattern is exactly reversed. Cold kills every occupant of the cooled area regardless of stage - eggs, larvae and pupae alike - and stops sharply where the cluster could still cover. Chilled brood therefore appears as a bounded contiguous patch containing all stages. Infectious disease kills scattered individuals according to susceptibility and stage, among healthy neighbours. Bounded and indiscriminate means environment; scattered and selective means pathogen.

Misconception: A spotty brood pattern means the queen is failing, so requeen. **Correction:** A spotty pattern is a sign with more than a dozen causes, and the most common actual answer in the field is heavy Varroa infestation with its virus complex. Requeening on a spotty pattern alone risks killing a good queen, wasting a purchased one, and leaving a mite load or a foulbrood infection entirely untouched. Examine the cells, test suspicious larvae, take a mite count, and consider colony history before deciding.

Misconception: European foulbrood does not really need attention because affected colonies usually recover when the flow comes. **Correction:** Spontaneous remission is real and is exactly what makes the disease deceptive. The organism persists on comb and in adult bees, and recurrence in later seasons is common. Sham-treated control colonies in a 2026 Canadian trial also gained some strength, though not significantly, while the treated colonies improved significantly - so improvement on its own is weak evidence that a treatment worked. Addressing the nutritional and managerial cause is what actually changes next year's outcome.

Misconception: Chalkbrood is a disease you treat, and the difficulty is that nothing is registered. **Correction:** Chalkbrood is fundamentally a thermoregulation and conditions problem. The fungus grows best at about 86 degrees F and is inhibited at the 95 degrees F a healthy brood nest holds, so it is chilling and colony weakness that create the disease from spores that are ubiquitous anyway. The effective interventions - correcting the site, improving ventilation and drainage, strengthening the colony, avoiding brood chilling, and requeening with hygienic stock - are all management, and no chemical treatment is needed or registered.

Misconception: White chalkbrood mummies and black ones are the same thing at different ages. **Correction:** *Ascosphaera apis* is heterothallic. Spore cysts form only where mycelia of the two mating types meet, so a white or grey mummy is largely sterile mycelium while a grey-green to black mummy is loaded with infective spores. Colour is a read on infective load, not merely on age, and the dark mummies are the ones worth the effort of removing.

Misconception: Stonebrood needs care because the hard mummies can cut your hands. **Correction:** The caution is microbiological. Stonebrood is caused by *Aspergillus* species - chiefly *A. flavus* and *A. fumigatus* - which are opportunistic human pathogens causing aspergillosis and, in the case of *A. flavus*, producers of aflatoxins. Handling sporulating comb aerosolizes spores. Gloves and respiratory protection are prudent, and anyone immunocompromised or with lung disease should not handle it at all.

Misconception: A negative lateral flow test rules out American foulbrood. **Correction:** The device detects antigen in the sample you put into it. A poorly chosen larva, a sample taken too early, or an old dried scale can all give a false negative, and the test says nothing about subclinical spore carriage. A negative device on a colony with ropy remains and adherent scale means the sample was bad. Lateral flow devices are excellent screening tools and are not laboratory confirmation.

Misconception: Drawn comb is such a bargain used that it is worth the small risk. **Correction:** Used comb of unknown history is the single highest-risk acquisition in beekeeping, because AFB spores in comb are viable for decades, cannot be removed by any cleaning process, and cannot be reliably detected by looking. The purchase price bears no relation to the potential cost of the apiary. Prefer woodenware without comb - woodenware can be sterilized, comb cannot - and check whether your state requires inspection or certification before used equipment changes hands.

Misconception: Hygienic stock makes a colony immune to foulbrood, so inspection matters less. **Correction:** Hygienic behaviour interrupts the pathogen's life cycle by removing affected larvae before sporulation. That reduces incidence substantially; it does not confer immunity, and a sufficient spore dose will still produce clinical disease. It also tracks brood diseases much better than Varroa, since detecting a dead larva is a different sensory problem from detecting a live mite under an intact capping. Hygienic stock complements inspection and biosecurity; a beekeeper who inspects less because the stock is hygienic has made things worse.

10.20 Self-Check Questions

- Explain, from the biology of *Paenibacillus larvae*, why a colony with an advancing American foulbrood infection can show completely normal entrance activity, and state what inspection practice follows from that fact.
- A single AFB scale contains on the order of a billion spores and the infective dose for a susceptible larva is under ten. Carry out the arithmetic and state, in one sentence, what conclusion about management it forces.
- Distinguish the remains left by American foulbrood from those left by European foulbrood on three axes - position in the cell, physical consistency, and adherence - and explain the physical reason the AFB scale cannot be lifted out.
- You find sunken, perforated cappings and a brown ropy strand in a colony in an eight-hive yard at 4 pm on a Saturday. Describe exactly what you do for the rest of that day and why each step matters.

- A colleague proposes to move a frame from a suspect colony into a strong neighbour to see whether the disease develops there, arguing that this is a controlled test. Give the two reasons this is wrong.
- Describe how to collect and package a brood sample for laboratory diagnosis, and identify the packaging error that ruins more samples than any other. Explain the mechanism by which that error destroys the sample.
- Why must a hive body be scraped free of wax and propolis before scorching, and what is the visible standard that tells you the scorching was adequate?
- *Melissococcus plutonius* forms no durable spore. Trace through at least four specific management consequences that follow from that single fact.
- Give the recurrence figures from the classic UK shook-swarm trial and explain what the difference between the two arms demonstrates about how European foulbrood should be approached.
- A colony in a shaded, poorly drained site in the coastal plain shows chalkbrood every spring. Set out your management response, and justify the absence of any chemical treatment from it - including the temperature relationship that explains why your interventions work.
- Distinguish the mortality pattern produced by chilling from that produced by infectious brood disease, and explain the mechanism behind each pattern. Give the field consequence of getting this backwards.
- List at least eight conditions that can produce a spotty brood pattern, and state why a beekeeper who requeens on seeing one is making a mistake.
- Explain what a test frame tests, how you interpret each of the two possible outcomes, and the one circumstance in which you must not use one.
- Explain the mechanism by which hygienic behavior confers resistance to American foulbrood and chalkbrood, and give two honest limitations of the trait.

10.21 Self-Check Answers

- Adults are not susceptible to *P. larvae*; only larvae in roughly their first day or two after hatching can be infected, because the young larva's midgut lacks a mature peritrophic membrane and its diet is undiluted glandular food. Adults ingest and distribute spores without harm. So the colony's foragers, guards and house bees behave normally while brood mortality accumulates inside sealed cells. The adult population declines only once brood loss has run long enough that replacement fails, by which point the colony has been distributing spores for months. What follows is that any assessment based on entrance activity or general vigour is worthless, and only careful cell-by-cell examination of the brood in good light will find the disease early.
- A billion spores divided by an infective dose of about ten gives roughly a hundred million infective doses in a single scale - more larvae than any colony rears in its existence, by orders of magnitude. The conclusion is forced: one scale is not a trace of past disease but an inoculum vastly exceeding anything the apiary could consume, no cleaning process can reduce it to a safe

level, and therefore management must be destruction of the infected material or a strictly controlled equivalent such as gamma irradiation, not colony-level treatment or improvement.

- AFB remains lie stretched flat along the lower cell wall extending toward the base; EFB remains are twisted, displaced or collapsed in abnormal positions. AFB remains draw out as an elastic brown thread of an inch or more; EFB remains are watery to pasty and break without elasticity. AFB scale adheres so firmly it crumbles rather than lifting; EFB remains lift out in one piece. The adherence has a mechanical explanation: during decomposition the AFB remains are semi-liquid and in intimate contact with the wax, and as the mass dries it shrinks onto and bonds to the cell wall. That is why affected comb can never be cleaned out and must be destroyed.

- Stop all movement immediately - no frame, bee, tool or box leaves that colony. Close the hive and reduce the entrance, because a failing colony is robbed out and robbing is the pathogen's best dispersal route. Scorch or bleach the hive tool, change or wash gloves, and treat the suit as contaminated. Inspect the remaining seven colonies to see how far it has gone, but do that work before contaminating yourself or on a separate visit, always working suspect colonies last. Contact the state apiary inspector and follow their direction, since AFB is reportable in most states and the inspector has statutory authority. Collect a sample as they direct. Do not feed antibiotics, do not extract, and do not move brood to test the diagnosis.

- First, it is not a test. The incubation interval is weeks, the result would be ambiguous, and a laboratory can answer the question definitively in days. Second, and decisively, it is a deliberate transmission event: the frame carries spores, and placing it in a healthy colony converts one infected colony into two. The whole logic of the containment rule is that most apiary-wide outbreaks are created by the beekeeper in the interval between suspicion and diagnosis, and this proposal is precisely that mistake carried out on purpose.

- Cut a piece of comb of about 4 square inches, or the size the receiving laboratory specifies, deliberately including cells with sunken or perforated cappings and any scale, and excluding honey. Wrap it in paper - newspaper or a paper bag - place it in a sturdy cardboard box so it is not crushed, and enclose a note with name, address, date, apiary location, hive identification and a description of what you observed. Notify the state inspector. The ruinous error is wrapping in plastic, foil or any airtight container: brood comb carries moisture, sealed samples sweat, and saprophytic moulds overgrow the comb within a day or two so that nothing can be read or cleanly cultured. Paper breathes and the sample arrives readable.

- Wax and propolis insulate the wood. When the flame is applied they melt and vaporize, absorbing the energy that would otherwise raise the wood surface temperature, so the surface beneath never reaches the temperature that destroys endospores. Scraping first removes that heat sink. The visible standard is uniform charring - a genuine dark char across every interior surface, including corners, joints and frame rests - not a light browning. If propolis remains you will see it boil; keep going. Frames and comb cannot be saved this way, and scorching cannot be used on polystyrene equipment at all.

- First, the pathogen does not persist in comb and woodenware for decades, so destruction of equipment is not required and comb replacement meaningfully reduces the reservoir. Second, because the mechanism is competition for larval food in the midgut, improving nutrition through feeding and better forage directly attacks the cause. Third, a brood break through requeening removes the susceptible stage for a period and interrupts transmission, which would

accomplish nothing against a spore reservoir. Fourth, a shook swarm is a legitimate and often decisive option, because moving bees to fresh comb genuinely separates them from the reservoir - which is exactly what it fails to do for AFB. A fifth consequence is that antibiotics have a defensible if limited role, since suppressing the vegetative organism is suppressing the only form that exists.

- Waite, Brown, Thompson and Bew (*Apidologie*, 2003) found within-season success of about 95 percent for shook swarm plus oxytetracycline and about 96 percent for oxytetracycline alone - effectively identical. The following year, recurrence was 4.8 percent in the shook-swarm-plus-oxytetracycline arm against 21.1 percent in the antibiotic-only arm, a difference that was suggestive rather than conclusive. The trial suggests that within-season improvement is a poor measure of success, because the antibiotic suppressed the bacteria present while leaving the contaminated comb in service. Only the shook swarm addressed the reservoir. The general lesson is that European foulbrood should be approached as a reservoir-and-nutrition problem, with antibiotics at most buying time.

- Correct the site: better drainage or a different location, morning sun rather than deep all-day shade, hive stands off the ground, a slight forward tilt so condensation runs out, and adequate ventilation. Strengthen the colony so its bees can cover and hold 95 degrees F over all the brood it is rearing; do not give a weak colony more brood area than it can warm, keep cool-weather inspections brief, and do not split the brood nest across boxes. Requeen with hygienic stock, which removes infected larvae before spore cysts form. Cull heavily affected comb and feed if nutrition is marginal. No chemical treatment appears because none is registered, and because *Ascosphaera apis* grows best around 86 degrees F and is inhibited at the 95 degrees F a healthy brood nest maintains - so restoring thermoregulation is the treatment.

- Cold does not select. Every occupant of the cooled zone dies regardless of stage, and mortality stops sharply at the boundary the cluster could cover, producing a bounded contiguous patch containing eggs, larvae and pupae together, typically at the nest periphery or on exposed comb. Infection kills whichever individuals received an infective dose during their window of susceptibility, which is probabilistic, so mortality is scattered among healthy neighbours and concentrated in the developmental stage the pathogen kills. Getting this backwards sends a beekeeper searching for a pathogen - possibly destroying equipment or dosing a colony - after their own long cool-weather inspection or an oversized split caused the loss.

- American foulbrood; European foulbrood; sacbrood; chalkbrood; chilled brood; heavy Varroa infestation with the associated virus complex; a failing or poorly mated queen; laying workers; inbreeding with removal of homozygous diploid drone larvae; a pollen- or honey-bound brood nest; and a plant toxin disorder such as purple brood from titi during its bloom. The mistake in reflexive requeening is that a spotty pattern is a sign and not a diagnosis. The most common actual cause in the field is mites. Requeening on the pattern alone can kill a sound queen, waste a purchased one, leave the real problem untouched, and introduce a new queen into a colony whose actual problem will kill her too.

- A test frame of eggs and very young larvae from a known-healthy colony, inserted into a suspect colony, separates a queen problem from a colony problem. If the introduced brood is reared to a good solid pattern, the cells and nurse bees are sound and the fault lay with the queen or her mating - requeen. If the introduced brood dies in the same way the colony's own brood was dying, the fault is in the colony: disease, comb contamination, pesticide, or chilling - and

requeening would have been useless. As a secondary use, emergency cells drawn on the frame confirm queenlessness. The prohibition: never use a test frame where American foulbrood cannot be excluded, since it moves comb from a healthy colony into a suspect one and you cannot get it back.

- Workers detect and uncap cells containing diseased brood and remove the larva before the pathogen reaches its infective stage. For American foulbrood, the larva is removed while the bacterium is still vegetative, before it sporulates - vegetative cells carried out of the hive are a dead end, whereas a larva left to dry into a scale becomes a billion spores. For chalkbrood, removal precedes formation of spore cysts, so the colony's spore load stops growing. The limitations: it is reduction, not immunity, and a heavy enough spore dose still produces clinical disease, so hygienic stock complements rather than replaces inspection and biosecurity. And it predicts brood-disease resistance far better than Varroa resistance, since detecting a dead larva is a different sensory task from detecting a live mite reproducing under an intact capping.

10.22 Further Reading

- Shimanuki H & Knox DA. *Diagnosis of Honey Bee Diseases*. USDA Agriculture Handbook No. 690, 2000. The standard American field reference for brood disease signs, sample submission and laboratory methods; freely available online and still the document most US inspectors work from.

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- World Organisation for Animal Health (WOAH/OIE). *Terrestrial Manual*, chapters on American foulbrood and European foulbrood. The international reference standard for diagnosis, including laboratory methods and the infective-dose and susceptibility-window figures.
- US Food and Drug Administration. *Guidance for Industry #213* (transition completed 1 January 2017) and the Veterinary Feed Directive final rule (80 FR 31708, 3 June 2015; effective 1 October 2015). The regulatory basis for veterinary oversight of antimicrobials in honey bees.
- Graham JM (ed.). *The Hive and the Honey Bee*. Dadant & Sons, 2015 edition. The disease chapters give the standard American treatment of brood disease diagnosis and management.
- Sammataro D & Avitabile A. *The Beekeeper’s Handbook*, 5th edition. Cornell University Press, 2021. Practical, well-illustrated coverage of brood disease recognition and equipment sterilization.
- Caron DM with Connor LJ. *Honey Bee Biology and Beekeeping*, revised edition. Wicwas Press. Clear treatment of brood disease at the level this exam targets.
- University of Florida IFAS Extension, EDIS AA138 (Chalkbrood Recommendations) and the IFAS honey bee disease series. Regionally appropriate for the southeastern US and freely available.
- University of Georgia Extension and the Georgia Master Beekeeper Program materials on honey bee diseases; Clemson Cooperative Extension and Auburn University Extension apiculture publications; NC State Extension Apiculture. All maintain current, regionally specific brood disease guidance and, importantly, current contact information for state apiary inspection programs.
- Honey Bee Health Coalition. *Tools for Varroa Management*, 9th edition, 2026. Not a brood disease document, but the mite count that belongs in every abnormal-brood investigation is described here.
- Bee Health (eXtension) - articles on foulbrood diagnostic kits and on purple brood. Short, current, and written for practitioners.

Chapter 11. Viruses, Nosema & Adult Bee Disorders

Covers exam questions Q199-Q213.

11.1 Orientation

Most of what a working beekeeper calls “my bees are sick” turns out, on investigation, to be one of four things: a virus amplified by Varroa, a Nosema infection invisible to the naked eye, a syndrome produced by the combined wreckage of a heavy mite infestation, or an adult bee disorder that mimics all of the above. Chapter 11 covers all four categories and the diagnostic reasoning that separates them.

The organizing idea is covert versus overt infection. Honey bees carry a remarkable catalogue of viruses all the time, at levels too low to cause visible harm. What pushes a colony from quiet carrier to clinical wreck is not usually the acquisition of a new pathogen but the disruption of the balance that keeps existing pathogens covert – and Varroa is the primary disruptor. Understanding this shifts the entire framing of viral disease management: because there is no registered treatment for any honey bee virus, the manageable lever is always the mite, and a beekeeper who learns to recognize viral signs without simultaneously running a mite count has learned the wrong lesson.

The second organizing idea is that the absence of visible signs does not mean the absence of disease. *Vairimorpha (Nosema) ceranae*, now the dominant microsporidian in honey bees across most of the world, typically causes no dysentery at all. Tracheal mites can suppress flight in spring dwindling colonies without producing the classic K-wing in every affected bee. Colony collapse disorder, as originally defined, was characterized by a colony that looked prosperous until it was suddenly empty. Diagnosis in this domain requires more than a walk past the front of the hive.

The third organizing idea is the dead-colony post-mortem. When a colony dies, the pattern of the corpse – where the bees are, what the brood looks like, whether stores remain, whether the stores were robbed – encodes a diagnosis. Learning to read dead colonies tells you what killed them, which tells you what to do differently. The examiner uses the diagnostic scenario as a way to test whether a candidate can integrate mechanism with observation. This chapter builds that skill explicitly.

11.2 The Viral Landscape: Covert and Overt Infection

More RNA viruses have been documented in honey bees than in any other social insect, partly because no other insect has been studied so intensively; the most prevalent and widespread are deformed wing virus, sacbrood virus, black queen cell virus and the acute bee paralysis complex (Beaurepaire and colleagues, Insects, 2020). Surveys using molecular methods routinely detect six or more different viruses in a single colony, and in the absence of a heavy Varroa infestation, most of those infections remain covert: the virus replicates at low levels, circulates in hemolymph and midgut fluid, passes from queen to eggs and from mouth to mouth among adults, and produces no visible signs. The bee’s immune system, fat body health, and nutritional status keep virus titers in check.

The transition from covert to overt infection is the clinical event. When viral titers rise by several orders of magnitude, bees emerging from capped cells carry viremia levels high enough to impair development

of neural circuits, shorten adult lifespan, and produce gross anatomical defects. The colony crosses from quiet carrier to visibly sick colony.

Varroa drives this transition in two distinct ways. First, it acts as a direct vector: the mite feeds on bee fat body during the phoretic phase, and during this feeding it injects virus directly into the bee's hemolymph. This bypasses the gut epithelium, which is a significant barrier to oral transmission, and delivers virus at a site where it contacts the fat body and developing tissues immediately. The result is circulating virus titers many times higher than oral exposure produces. Second, Varroa feeding damages the fat body itself – the organ that is simultaneously the bee's nutritional reserve, detoxification system, and primary immune tissue. A bee with a compromised fat body controls viral replication less effectively at any given viral dose.

The practical consequence is that a positive virus test result is uninformative in isolation. Almost every colony will test positive for deformed wing virus, sacbrood virus, and several others at any given time. The clinically relevant question is not whether the virus is present but what the mite population is, because mite level predicts whether the colony will tip from covert carriage to overt disease.

11.3 Deformed Wing Virus: The Dominant Player

Deformed Wing Virus (DWV) is the most consequential honey bee virus in managed beekeeping today, not because it is uniquely lethal but because Varroa is an efficient vector for it and because Varroa is ubiquitous. The virus exists as two main strains. DWV-A was the first described. DWV-B emerged as a genetically distinct variant, has spread globally since Varroa spread, and appears to be better adapted to Varroa-mediated transmission. In the 2024-25 US colony loss event – the worst on record at 55.6% annual loss – DWV-B was detected in 100% of symptomatic bees examined, and DWV-A was present in 78% of screened colony samples. The same study found the Y215H amitraz-resistance mutation in all 39 mites it genotyped, drawn from 18 colonies in five commercial operations. The study shows association rather than proof of cause, but the plausible link is this: treatments failing against resistant mites let mite populations reach the levels that drive overt viral disease across entire operations.

The overt signs of DWV are familiar: workers emerging from capped cells with shriveled, crumpled wings, shortened and rounded abdomens, and bodies that are often slightly darker than normal. These bees cannot fly. They crawl at the hive entrance and die within days. The deformity results from viral interference with pupal wing development: the developing wing tissue is invaded by virus during the capped cell stage, when the mite is feeding and transmitting most intensively. The result is structural, not simply physiological – the wing never forms correctly and cannot be repaired.

What is less visually obvious but equally important is the effect of DWV on bees that emerge without visible deformity. A bee can carry a covert DWV infection that nonetheless measurably impairs its learning rate, navigation accuracy, and lifespan. Studies exposing pupae to DWV at doses that do not produce wing deformity find that resulting adults are worse at associative learning tasks, return less reliably from foraging trips, and die sooner than uninfected controls. This means that even a colony with no visibly deformed bees at the entrance may be carrying enough covert infection to reduce foraging efficiency – a subclinical drag on performance that compounds over the summer.

Viremia at emergence: bees already carry detectable viral loads when they eclose from capped cells, reflecting infection acquired during the capped stage. The load they carry at emergence partly predicts their adult trajectory.

Because there is no registered treatment for DWV or any honey bee virus, managing DWV means managing Varroa. A beekeeper who sees bees with deformed wings should treat it as a mite problem, not a disease problem requiring a pharmaceutical response. The correct sequence is: observe visible deformity – run an immediate mite count – act on the count, almost certainly with emergency treatment given that visible deformity indicates a mite load that has already caused serious damage.

11.4 Acute Bee Paralysis Virus and Israeli Acute Paralysis Virus

Acute Bee Paralysis Virus (ABPV) produces a rapid-onset adult syndrome characterized by trembling, shaking, and inability to fly. Affected bees may cluster on the ground near the hive entrance or on the bottom board. The colony can lose substantial numbers of adults rapidly. ABPV is transmitted by Varroa and the 2024-25 loss event data show it was detected in 72% of screened colonies, at a level unusually high relative to prior surveys. ABPV loads did not differ between weak and strong colonies, so the study does not show that ABPV, or the mite surge, caused the collapse; the symptomatic individual bees carried much higher DWV-A and DWV-B.

Israeli Acute Paralysis Virus (IAPV) is related to ABPV and was initially proposed as a candidate cause of Colony Collapse Disorder in 2007. Subsequent research did not sustain that specific causal claim, but IAPV remains a Varroa-vectored virus with the capacity to produce significant adult mortality. Its overt presentation involves flightless, shaking bees near the hive entrance. Its prevalence in a colony rises with mite loads, following the same pattern as DWV.

Kashmir Bee Virus (KBV) rounds out this family. It is extremely virulent in laboratory experiments, killing caged bees within days of oral exposure at doses that other viruses survive. In the field, overt KBV disease is uncommon and KBV appears to persist mostly as a covert infection. It is worth knowing as a name and concept because its lab virulence contrasts sharply with its field behavior, which illustrates how much the colony context modulates viral outcome.

11.5 Chronic Bee Paralysis Virus: Two Syndromes

Chronic Bee Paralysis Virus (CBPV) is in a different category from the Varroa-vectored viruses. It does not require a mite vector and is not amplified by mite pressure. Instead, it spreads by direct contact between adult bees – including transmission through feces contaminating surfaces in a crowded colony – and its outbreaks are characteristically associated with overcrowding or prolonged confinement.

CBPV produces two distinct clinical syndromes, and recognizing both is a master-level expectation because each can be mistaken for an unrelated condition.

11.5.1 Type 1: Trembling, Bloated Syndrome

In the first syndrome, affected workers are unable to fly, tremble or shake when handled or disturbed, crawl on the ground or up grass stems near the hive, and often have distended abdomens. Wings may

be spread at abnormal angles. The bees may be partially paralyzed. Dead bees accumulate in front of the hive. A colony in the grip of a Type 1 CBPV outbreak loses visible numbers of adult workers over days to weeks.

This presentation overlaps considerably with acute pesticide poisoning – particularly neonicotinoid or organophosphate exposure – in that both produce crawling, trembling, flightless bees in front of the hive. The distinction matters profoundly because a pesticide incident calls for immediate documentation, sample collection, and regulatory reporting, while a CBPV outbreak calls for reducing crowding and, if the problem persists, looking for other concurrent problems (requeening is traditionally suggested but has no robust evidence of benefit). Distinguishing features: pesticide casualties typically appear suddenly after a nearby application, affect all hives in the yard simultaneously, and often include bees with extended proboscises; CBPV tends to develop more gradually, may affect some colonies more than others, and the paralysis tends to be progressive within individuals.

11.5.2 Type 2: Hairless Black Syndrome

In the second syndrome, affected workers have lost most of their body hair, giving them a dark, shiny, greasy appearance. Guards inside the hive often harass or reject these bees, which adds to the scene of apparent chaos. The hairless bees may otherwise look physically intact but are unable to defend themselves against the rejection behavior.

This presentation overlaps with the normal aging trajectory of forager bees, which do lose hair with wear over their lifespan, and it also overlaps superficially with bees darkened by pesticide exposure. Hairless black syndrome in CBPV is distinguished by the simultaneous occurrence of harassed bees at the entrance, younger-appearing bees inside showing no such change, and a colony pattern consistent with crowding or confinement. An isolated aging forager with thin hair is normal; a significant cohort of shiny, dark, rejected bees at the entrance of a packed colony is a signal.

Both CBPV syndromes arise from the same virus and can co-occur. Management is non-pharmaceutical and the evidence is thin: add space to reduce crowding, ensure a good pollen supply and ventilation, and remove dead bees. Requeening is traditionally recommended but has no robust evidence of benefit (any effect may reflect the brood break); a modified shook swarm has shown early promise. Outbreaks often subside as conditions change, but affected bees die within days, and a colony that continues to decline despite adequate space warrants analysis of whether other concurrent problems exist.

11.6 Sacbrood Virus, Black Queen Cell Virus, and the Brood Connection

Two viruses connect the adult virus story of this chapter to the brood disease story of the preceding one.

11.6.1 Sacbrood Virus

Sacbrood Virus (SBV) is included here because its etiology is viral, and that etiology determines both its management and its prognosis. The presentation is a brood disease: larvae fail to pupate after capping, lie extended on their backs with the head end raised toward the cell opening, and as the infection

progresses change from white through yellow-brown to dark brown. When a finger probe lifts the body, it pulls free as a fluid-filled sac – hence the name. The sac forms because the virus prevents the larva from shedding its final larval cuticle at pupation; the shed fails to occur, the exuvial fluid accumulates between the unshed cuticle and the body, and the intact skin holds the fluid like a bag. Dried remains form a brittle, gondola-shaped scale curled upward at the head end, which removes cleanly from the cell with a probe.

The differential from American Foulbrood is critical and frequently tested. AFB remains are ropy – a match or toothpick drawn through them stretches into a thread an inch (about 25 mm) or more before breaking. Sacbrood remains are not ropy. AFB has a distinctive glue-pot odor; sacbrood has no characteristic odor. AFB scales adhere to the lower cell wall and cannot be removed intact; sacbrood scales lift free easily. Both diseases kill larvae after the cell is capped, and both can leave sunken or perforated cappings, so the cappings alone do not separate them; the remains do. An AFB larva collapses into a coffee-colored, ropy mass; a sacbrood larva lies on its back with its head raised and lifts out whole as a fluid-filled sac.

Sacbrood has no specific treatment. Colonies with strong populations typically suppress the problem as house bees remove infected larvae. The response is nutritional support, requeening if the condition persists through multiple brood cycles, and maintenance of colony strength.

A more virulent variant, Chinese Sacbrood, has been documented in *Apis cerana* in Asia and produces more severe outbreaks. Standard SBV in *Apis mellifera* is generally self-limiting.

11.6.2 Black Queen Cell Virus

Black Queen Cell Virus (BQCV) kills queen pupae and prepupae within their cells, causing the cell wall to turn dark brown to black. The name reflects the visible darkening of the wax cell itself, not just the contents. BQCV has a documented association with Nosema infection – first shown with *Vairimorpha apis* and since reported with *V. ceranae* – in the same colonies, though the mechanism of the association is not fully established. One proposed model is that Nosema infection suppresses the immune response of nurse bees or emerging queens in ways that allow BQCV to reach lethal titers in developing queens, but co-infection has mainly been shown in laboratory work, and a causal role for Nosema in queen-cell losses has not been demonstrated.

For queen producers, this association has direct practical implications. Unexplained losses of sealed queen cells, particularly in spring when Nosema is often most prevalent, should prompt assessment of the nurse-bee source colony for Nosema by microscopy, alongside a review of grafting technique, nutrition and handling. A queen-rearing operation losing cells at rates that cannot be explained by handling errors should test for BQCV and assess Nosema status in the colony being used to build cells. Grafting hygiene and cell-handling temperature matter, but they are not the only explanations when cells die sealed.

11.7 The Nosema Microsporidians: Taxonomy and Two Species

Nosema in honey bees is caused by a microsporidian, not a bacterium and not a virus. This is the single most important classificatory fact about Nosema, because it explains directly why antibiotics have no

effect on it: microsporidians are fungi-related organisms that form infective spores and infect the midgut epithelium.

11.7.1 Taxonomy in Transition

In 2020, a taxonomic revision reassigned both *Nosema apis* and *Nosema ceranae* to the genus *Vairimorpha*, producing the formal names *Vairimorpha apis* and *Vairimorpha ceranae*. The revision has been contested in the subsequent literature – a 2024 critique (Bartolome et al.) argued the revision was flawed, whereas a 2025 phylogenomic analysis (Bojko et al.) supported placing both species in *Vairimorpha* while keeping "nosemosis" as the disease name. Both naming conventions remain in active use in the primary literature.

The defensible position for a master-level candidate: write *Vairimorpha (Nosema) ceranae* on first mention, acknowledge that literature is split on the revision, and do not treat either name as an error on an examination. The underlying biology is identical regardless of which name is used.

11.7.2 Two Species, Different Histories

Vairimorpha (Nosema) apis is the species originally described in honey bees and has been known since the early twentieth century. It parasitizes the midgut ventriculus, forms relatively large oval spores detectable under a compound microscope, and is transmitted by ingestion of feces from infected bees. Its classical presentation includes spring dysentery: fecal spotting on the hive front, top bars, frames, and landing board, with brown or yellowish streaks of liquid feces. Colonies weakened by *V. apis* in late winter or early spring may show significant dysentery after confinement, with obvious contamination of the hive interior. The mechanism is straightforward: *V. apis* disrupts midgut epithelium function, reduces nutrient absorption, and appears to interfere with normal digestion of pollen.

Vairimorpha (Nosema) ceranae was originally identified in the Asian honey bee *Apis cerana*, as its name implies, and was found in *Apis mellifera* colonies in Spain in 2006. Since then it has spread globally and has largely displaced *V. apis* throughout most of the world, including the United States. Its spores are smaller and slightly more elongated than those of *V. apis* under the microscope, but the difference is difficult to determine reliably with light microscopy alone; molecular methods (PCR) are necessary for species-level diagnosis.

The most critical clinical difference between the two species is this: *V. ceranae* typically causes little to no dysentery. A colony can carry a heavy *V. ceranae* infection with a clean hive front and no visible fecal spotting. The absence of dysentery does not mean the absence of Nosema. This is one of the most significant and persistently misunderstood features of *ceranae*, and examinations test it directly.

11.8 Nosema Pathology: What the Microsporidian Does

Both species attack the columnar epithelial cells lining the ventriculus (midgut). After spores are ingested with contaminated food or water, they germinate and inject the sporoplasm into epithelial cells. The parasite then reproduces inside those cells, eventually killing them and releasing new spores into the gut lumen.

The functional consequences are:

Disrupted nutrient absorption. The ventriculus is where proteins from digested pollen are absorbed. With infected epithelial cells dying and being replaced, absorption efficiency drops. Infected bees may consume more food in an attempt to compensate but still remain protein-deficient. The physiological consequence mimics protein starvation even when food stores are present.

Suppressed immune response. Some studies report that *V. ceranae* down-regulates parts of the bee's immune response, but results vary with the genes measured, feeding and conditions. Where it occurs, this suppression may contribute to increased susceptibility to other pathogens, including the viral agents covered earlier in this chapter.

Shortened adult lifespan. Infected foragers die sooner than uninfected controls. In a colony where the forager population turns over faster than replacement bees mature, the workforce shrinks. The colony appears to decline from the outside – fewer foragers returning, declining stores in mid-season – in a pattern that can be mistaken for other causes.

Hypopharyngeal gland disruption. There is evidence that *ceranae* infection reduces the size and function of hypopharyngeal glands, which are the organs that produce brood food. This may impair nurse bee function and slow brood rearing, compounding the population effects.

The colony-level consequence of heavy *V. ceranae* infection is typically not sudden collapse but gradual weakening of the adult population through shortened lifespan, reduced nurse function, and increasing vulnerability to concurrent stressors. A colony that appears to be declining for no clear reason in midsummer, with no obvious Varroa problem and no brood disease, is worth sampling for Nosema.

11.9 Diagnosing Nosema: The Microscopy Procedure

Confirming Nosema requires microscopy. There is no reliable field test. The procedure:

Which bees to collect. Sample 30 to 60 bees from the hive entrance or the landing board, preferably bees that appear to be returning foragers or older workers. Young house bees have lower infection rates even in heavily infected colonies because spore loads accumulate with age and repeated exposures. Pooling young bees with old bees in a sample underestimates the true infection level. If the goal is monitoring a colony over time, consistent sampling of the same class of bees – entrance bees in the warmest part of the afternoon – gives the most comparable results.

Sample preparation. Place the bees in a container and add water, about 1 mL per bee. Crush the abdomens thoroughly with a pestle or the back of a spoon. Strain or pour a drop of the suspension onto a glass slide and add a coverslip.

Microscopy. Examine under a compound microscope at 400x magnification. Nosema spores appear as uniform, oval to oblong, highly refractile (bright, shiny) bodies about 3-6 micrometers in length, resembling grains of rice. At 400x in a well-prepared wet mount, they are unmistakable. Do not confuse pollen grains, bacterial cells, or yeast cells with Nosema spores; spores at 400x are distinctly larger and more refractile than bacteria and more uniform in shape than pollen.

Quantification. To get a spore count, use a hemocytometer – the same device used in clinical laboratories to count blood cells. Load the hemocytometer with a defined volume of the suspension,

count the spores visible in the counting grid under the microscope, and calculate the concentration, then express as spores per bee. About 1 million spores per bee is the commonly used level of concern; counts of several million or more are seen in heavily infected or collapsing colonies. The 1 million figure is an arbitrary, not validated, threshold, and spore count correlates imperfectly with colony harm.

Limitations of the method. Three are worth stating explicitly for the exam. First, light microscopy cannot distinguish *V. ceranae* from *V. apis* by spore morphology with confidence; the spores are different in size and shape on average but not reliably enough for routine diagnosis. Molecular testing (PCR) is required for species identification. Second, a composite spore count is a colony average and conceals the distribution across individuals: a few heavily infected bees in a mostly clean sample produces a moderate count, while a colony in which most bees carry low loads produces the same number. Third, spore counts vary seasonally, diurnally, and with the class of bee sampled, so a single count without context has limited meaning; consistency of sampling method matters if counts are to be compared over time or across colonies.

11.10 Treatment and Management of Nosema

Fumagillin has for decades been, and remains, the only product marketed for Nosema control in honey bees. It is an antibiotic-related compound (produced by a fungus, Aspergillus fumigatus) that inhibits a methionine aminopeptidase enzyme critical to the parasite's replication. It does not kill spores directly; it suppresses the active replication phase within living bees. This means two things matter. First, fumagillin degrades relatively quickly in syrup solution and should not be made up far in advance (the label says to feed the medicated syrup within 24 hours). Second, and more importantly, fumagillin does not sterilize comb. Spores deposited in comb from infected bees remain viable and infective; bees restocked onto treated comb or raised in cells lined with old fecal material are immediately re-exposed. The comb reservoir is the reason Nosema control cannot rest on drug treatment alone.

Fumagillin (sold in the US as Fumidil-B and Fumagilin-B) remains commercially available over the counter, sold by the major beekeeping supply houses, but current US labels list it as an unapproved animal drug that FDA has not found to be safe and effective. A 2018 closure of the original maker (Medivet) created a real, widely-discussed supply disruption; supply resumed with Fumidil-B (KBNP, 2022) and Fumagilin-B (Vita Bee Health, 2024). Because it does not sterilize comb, it should never be relied on alone — the non-pharmaceutical approaches below matter whether or not fumagillin is part of the plan. Thymol-based products have been studied in research contexts but are not registered for Nosema control in the United States as of 2026, and the evidence for their efficacy is not yet conclusive enough to recommend as a substitute.

Non-pharmaceutical management approaches (essential alongside fumagillin, not just instead of it):

Comb management. Spores persist on wax comb for months to years. Regular rotation and replacement of comb – culling frames older than three to five years – removes the oldest and most contaminated comb from the cycle. Acetic acid fumigation of empty comb (concentrated acetic acid evaporated in sealed boxes) can kill Nosema spores but requires careful handling, adequate sealing, and awareness

that it corrodes metal fittings. Gamma irradiation of comb sterilizes spores effectively but requires access to an irradiation facility, which is not available to most beekeepers.

Colony strength. Strong, well-fed colonies tolerate Nosema infection better than weak ones. Maintaining protein stores, supplementing with pollen patties when natural pollen is scarce, and avoiding management practices that leave colonies depleted of young bees all reduce the impact of infection even when spore counts are high.

Requeening. Requeening provides a brood break that temporarily reduces the number of nurse bees cycling through infected cells. New queens produce a fresh cohort of workers. If the infection is driven by genetics that affects hygienic behavior, requeening to better stock can improve outcomes.

Ventilation. High humidity in the hive favors spore survival and can worsen fecal contamination during confinement. Screened bottom boards and adequate upper ventilation reduce ambient humidity and limit moisture accumulation in stored combs.

Avoiding stored damp pollen. Damp pollen stored in cells ferments and may carry high spore loads. Colonies with waterlogged pollen stores in spring after a wet winter face elevated Nosema exposure early in the buildup season.

Feeding location and cleansing flights. Colonies able to take regular cleansing flights reduce fecal accumulation inside the hive. Bees confined for weeks during prolonged cold spells accumulate feces and contaminate surfaces that bees contact repeatedly. Where winter confinement is prolonged, protecting the colony from wind while allowing any midwinter warm spell to permit flight reduces interior contamination.

11.11 Adult Bee Disorders

For the life cycle, pathology, diagnosis and current status of the tracheal mite (Acarapis woodi), see Chapter 12, Section 12.12, “Tracheal Mites: The Internal Acarine Parasite.”

11.11.1 Dysentery as Syndrome, Not Disease

“Dysentery” in honey bees refers to the symptom of liquid fecal discharge inside or in front of the hive, not to a specific disease. Multiple conditions produce dysentery, and the response depends on which one is operating.

Vairimorpha apis infection is one cause, producing the classic spring dysentery pattern after winter confinement. But dysentery also occurs when bees consume stores with high water content or poorly digestible solids – fermented honey, granulated honey with moisture absorbed over winter, dilute syrup fed in autumn that did not concentrate properly, or honeydew stores that are higher in indigestible oligosaccharides than floral honey. Extended confinement during cold or wet spells that prevent cleansing flights causes bees to void their fecal load inside, producing streaking on frames, top bars, and the inner cover. Dysentery in this context is not an infection at all but a consequence of the bee’s biology: bees cannot excrete feces during normal colony life in winter and must await a flight opportunity.

Recognizing dysentery as a symptom rather than a disease matters for management. A colony with spring dysentery that has access to cleansing flights and appropriate stores will often resolve the problem without intervention. Treating empirically for Nosema based on fecal spotting alone risks treating a colony that does not have Nosema, while failing to identify the actual problem – fermented stores, prolonged confinement – that needs to be addressed.

11.12 Parasitic Mite Syndrome

Parasitic mite syndrome (PMS) is a descriptive clinical term, not a discrete disease entity. It refers to the constellation of brood and adult pathology produced by a heavy Varroa infestation operating through its associated viruses, particularly DWV. The picture in a heavily mite-infested colony late in the season includes: irregular brood pattern with empty, discolored, and sunken cells; larvae dying in varied positions, some of which superficially resemble foulbrood without the ropiness, the characteristic odor, or the hard adherent scale; adult bees with deformed wings crawling at the entrance; and a rapidly declining adult population.

This pattern matches no single classical disease description, which is why field diagnosis is difficult without a mite count. The term was coined to capture the clinical reality that Varroa-mediated damage produces a complex syndrome, not a single sign. For the exam, its value is conceptual: recognizing the pattern directs the beekeeper to run a mite count and apply treatment, rather than sampling for a novel bacterial pathogen or attempting antibiotic therapy.

Mite fecal deposits – white specks on the upper inner walls of vacated brood cells – are a useful post-mortem finding that confirms mite activity in brood cells, helping distinguish PMS from foulbrood when the adult population is gone and the brood damage is the only finding available.

11.13 Colony Collapse Disorder: A Precise Definition

Colony Collapse Disorder (CCD) as defined in the scientific literature of approximately 2007-2010 is a specific syndrome characterized by rapid loss of the adult bee population with several distinctive accompanying features. The defining pattern:

- The adult population disappears rapidly or over a short period.
- A laying queen is present in the remnant colony.
- Capped brood is present, often in substantial quantity.
- Honey and pollen stores are present.
- Dead adult bees are largely absent, either inside the hive or near the entrance.
- The abandoned stores are not robbed by neighboring colonies or immediately infested by hive beetles or wax moths – a finding attributed to a chemical or behavioral deterrent associated with the affected bees, though the mechanism was never established with certainty.

The delayed robbing of abandoned stores was one of the more operationally distinctive elements and helped field reporters identify CCD cases, since a dead colony that gets robbed immediately is common; one that sits unrobbed for days is unusual.

No single cause of CCD was identified. The consensus treats it as multifactorial, involving some combination of Varroa, viruses, pesticide exposure, nutritional stress, and possibly an interaction that researchers were unable to fully disentangle given the complexity of field conditions. Reported CCD incidence declined after its peak in roughly 2006-2008. The widely quoted figure of 55-56% annual colony loss in the United States reflects current high rates of colony loss, but most of that loss does not meet the CCD case definition. The two should not be conflated.

For the exam: CCD is defined by what is absent (most adult bees, dead bees near the hive) in the presence of what should not remain (queen, brood, stores, uninvaded comb). Using CCD as a synonym for any colony loss is an error that examinations test directly.

11.14 Isolation Starvation: Reading the Dead Colony

A winter colony found dead with abundant capped honey elsewhere in the box and a small cluster of dead bees with heads extended into empty cells presents a diagnostic scenario that integrates virus, Varroa, nutrition, and winter biology.

This is isolation starvation: the cluster starved while surrounded by food it could not reach. The thermodynamics of winter cluster formation explain the mechanism. As outside temperatures fall below approximately 57 degrees F, bees form a compact spherical cluster and generate heat by isometric muscle contractions. The cluster can maintain its core temperature, but it cannot move laterally across cold comb to reach stores that are not physically contiguous with the current cluster position. If the cluster is small – too few bees – it cannot generate enough warmth to allow even a short lateral movement across a gap of cold comb. It contracts, starves in place, and dies with its heads in empty cells while frames of capped honey sit a foot away.

Why was the cluster small? This is the question that separates a surface diagnosis from a master-level one. The cluster size in December and January reflects the adult bee population that entered winter, which in turn reflects the quality and abundance of the late-summer and early-autumn brood cohort. Varroa-infested colonies with high mite loads in July and August produce an autumn bee cohort whose bees carry heavy viral loads, particularly DWV, from infestations occurring in their pupal cells. These bees emerge with compromised fat bodies, shorter lifespans, and impaired ability to physiologically prepare for winter. The cluster that enters November is already small and contains bees that are not in optimal winter condition. By January, bees continue dying and the cluster shrinks further. Isolation starvation is often the proximate cause of death; Varroa and DWV are usually the underlying cause of the small cluster.

Reading a dead colony for this scenario: look for white mite fecal spots (small white specks) inside vacated brood cells on the upper cell walls; look for the characteristic balled posture of the cluster position at death; look for any deformed-winged bees among the dead; examine whether the remaining stores are sound or show granulation and moisture damage. A cluster that died of isolation starvation in

a colony with no concurrent mite problem looks different from a cluster that died of the same proximate cause in a mite-damaged colony, and the difference in the post-mortem findings tells you which situation you have.

11.15 Viral Disease Management: Integrating the Chapter

Because no treatment exists for any honey bee virus, the management of viral disease is the management of its drivers and modulators. The following measures each address a specific mechanism:

Control Varroa above all else. Mites are the primary vector for the clinically significant viruses – DWV, ABPV, IAPV – and are the primary cause of the fat body damage that reduces immune competence. Keeping mite populations below treatment thresholds converts overt infections back to covert ones. Post-treatment mite count verification is essential; in the 2024-25 collapse study all 39 mites genotyped, from 18 colonies in five commercial operations, carried the Y215H amitraz-resistance mutation, against 66% in an earlier regional survey. Resistance is widespread and at or near universal in some operations, meaning treatment application without a post-treatment count is not treatment – it is the illusion of treatment.

Maintain nutrition. Bees with access to diverse, high-quality pollen produce well-provisioned fat bodies with functional immune systems. The association between pollen diversity (not just pollen quantity) and immune gene expression is documented in the primary literature. Where natural pollen is unavailable or the colony is in a pollen gap, high-quality pollen supplement reduces the immune deficit.

Requeen chronically affected colonies. Requeening changes the viral dynamics in several ways: it provides a brood break that interrupts mite reproduction; it replaces aged, potentially infected workers with a new cohort; it introduces different genetics that may be more resistant or hygienic; and it eliminates queen-to-egg viral transmission from a queen that may be transmitting high-titer covert infections.

Reduce crowding for CBPV specifically. CBPV outbreaks are linked to overcrowding and prolonged confinement. Adding space – supers, splits, or swarm prevention measures – reduces contact-mediated transmission.

Cull heavily infected brood comb. Moving brood comb from a collapsing, virus-ridden colony into a healthy colony introduces the virus and the mites associated with it. Removing and destroying severely affected comb removes one transmission route.

Disregard products claiming direct antiviral action. No product registered for use in honey bees has been demonstrated in peer-reviewed trials to reduce honey bee viral titers in a colony. A candidate who encounters a product marketed for bee “immune support” or “viral resistance” should evaluate it against that standard.

11.16 Numbers to Know Cold

Figure	Value	Why it is that value
DWV-B prevalence in symptomatic bees, 2024-25 event	100%	Consistent with mite populations, poorly controlled by amitraz, driving intensive pupal infection with DWV-B (an association, not a proven cause)
DWV-A prevalence, pooled colony samples, 2024-25	78% of colonies (113 sampled)	Most prevalent virus in pooled samples; DWV-B was in 100% of 39 symptomatic individual bees (an association with mite pressure, not a proven cause)
ABPV prevalence, 2024-25 event	72% of colonies	Unusually high relative to prior surveys; loads did not differ between weak and strong colonies, so it is not shown to be the cause of collapse
Age limit for tracheal mite susceptibility	<4 days old	Young bees lack the defensive behavior/chemistry that blocks mite entry into spiracles
Nosema spore count threshold (significant)	~1 million spores per bee	Empirical threshold from hemocytometer surveys; not a sharp clinical cutoff
Nosema spore count (heavy infection)	Several million or more per bee	Seen in heavily infected or collapsing colonies; no validated cutoff, and counts correlate imperfectly with colony harm
Sample size for Nosema assessment	30-60 bees	Enough to represent the colony average; foragers or entrance bees preferred
Microscope magnification for Nosema spores	~400x	Spores are 3-6 micrometers; visible and countable at this magnification
DWV-A vs DWV-B	2 strains	DWV-B associated with Varroa-adapted, more efficient transmission
V. ceranae spore size relative to *V. apis*	Smaller, more elongated	Spore morphology difference detectable microscopically but not reliably species-diagnostic
K-wing relevance	Associated with tracheal mites	Hindwing displaced from forewing coupling; also appears without tracheal mites
CBPV syndromes	2 (Type 1 and Type 2)	Same virus, different manifestations depending on route, dose, and colony context
CCD hallmark	Adults absent, queen present, stores unrobbed	The delayed robbing of intact stores was the operationally distinctive element
Colony loss rate, 2024-25	55.6%	Highest on record; amitraz-resistant mites and viral amplification are suspected contributors (association, not proven cause)
Colony loss rate, 2025-26	39.9% (preliminary; 95% CI 30-53%)	Decline from record but still roughly double the beekeepers' acceptable rate of 15-20%

Figure	Value	Why it is that value
Fumagillin status in US	Marketed (OTC) but listed as an unapproved animal drug	The only Nosema product available; 2018 manufacturer closure caused a supply gap, with successor products since 2022/2024; does not sterilize comb

11.17 Common Misconceptions

Misconception: If I see bees with deformed wings at the entrance, I should treat the colony for a wing disease with an appropriate medication. **Correction:** Deformed wing virus has no registered treatment. There is no antibiotic, antiviral, or other registered pharmaceutical that addresses bee viruses. Deformed wings are a sign that Varroa infestation has reached a level that is converting covert DWV into overt disease. The correct response is an immediate mite count and, almost certainly, emergency mite treatment. The "disease" is the mite load.

Misconception: My hive front is clean, so my bees do not have Nosema. **Correction:** *Vairimorpha (Nosema) ceranae*, now the dominant Nosema species in North America, typically produces little to no dysentery. A colony can carry millions of spores per bee with no visible fecal spotting on any surface. The reverse error is equally important: fecal spotting on the hive front does not confirm Nosema; dysentery has multiple causes including fermented stores, dilute syrup, and confinement without cleansing flights. Diagnosis requires microscopy.

Misconception: Fumagillin will clear up a Nosema problem if I feed it in syrup. **Correction:** Fumagillin suppresses the replication of the parasite within living bees and reduces the active infection. It does not kill Nosema spores in comb. Bees raised in or foraging over contaminated comb are immediately re-exposed after treatment ends, and the colony typically returns to high spore counts. Treatment without comb management addresses only half the problem.

Misconception: Brown fecal streaks on the top bars in March mean the colony has *V. apis* and should be treated for Nosema. **Correction:** Fecal streaks in early spring are a common finding with multiple causes. Prolonged confinement in cold weather causes bees to void inside regardless of whether they have Nosema. Fermented or high-water-content stores produce dysentery. *V. ceranae* can produce some dysentery but is also often symptomless. Treat the observation as a signal to sample for Nosema by microscopy, not as a confirmed diagnosis.

Misconception: Sacbrood is a bacterial disease like foulbrood and can be treated with an antibiotic. **Correction:** Sacbrood is caused by a virus. No antibiotic has any effect on a viral infection. Sacbrood is generally self-limiting in a strong colony and requires no pharmaceutical intervention; the response is nutritional support, maintenance of colony strength, and requeening if the problem persists through multiple cycles.

Misconception: The beekeeper next door lost colonies to Colony Collapse Disorder – that must be what's killing bees in my area. **Correction:** CCD is a specific syndrome with a specific case definition: rapid adult disappearance, laying queen present, capped brood present, stores present, minimal dead bees, delayed robbing. Most current colony loss does not meet this definition. Colonies that die over

winter with small clusters, collapse in summer from mite loads, or dwindle from disease are not CCD. Using the term loosely confuses the discussion and leads to incorrect conclusions about cause and prevention.

Misconception: Chronic bee paralysis virus is spread by Varroa mites, so the same mite management that controls DWV will control CBPV. **Correction:** CBPV is not vectored by Varroa. It spreads by direct contact between adult bees and through fecal contamination, and its outbreaks are associated with crowding, not mite pressure. Mite management will not prevent or resolve a CBPV outbreak. The specific intervention is reducing crowding; requeening is traditionally suggested but has no robust evidence of benefit.

Misconception: Hairless, shiny, dark bees in front of the hive are old foragers that are simply worn out. **Correction:** Foragers do lose hair with age and can appear somewhat darker as a result, but a significant cohort of hairless, shiny, "greasy" bees being harassed by guards at the entrance is characteristic of CBPV Type 2 (hairless black syndrome). The guard behavior – rejection of affected nestmates – is a specific clinical sign that distinguishes this from normal forager aging.

Misconception: If a colony was treated for Varroa and shows no deformed wings, viruses are not a concern. **Correction:** A treatment that failed due to resistance or improper application allows mite populations to continue growing, even if the beekeeper believes the colony has been treated. In the 2024-25 collapse study, all 39 mites genotyped from commercial operations carried the Y215H amitraz-resistance mutation, and resistance is widespread. Post-treatment mite counts are required to confirm efficacy; absence of visible deformed wings does not confirm low mite load or low viral titer.

Misconception: Isolation starvation means the beekeeper did not leave enough honey in the hive going into winter. **Correction:** Isolation starvation can occur with abundant stores present – the defining scenario is a small cluster that cannot move to reach stores just frames away. A colony may starve in the midst of plenty because the cluster shrank too much to bridge the gap between consumed stores and remaining stores. The root cause of a small cluster is usually Varroa and DWV damage to the autumn bee cohort, not a shortage of stores. Leaving more honey does not prevent recurrence if the mite problem is not addressed.

Misconception: Black queen cell virus is just a problem with grafting technique. **Correction:** BQCV is a viral pathogen with a documented association with Nosema infection in the source colony. Co-infection with Nosema and BQCV worsens outcomes in laboratory work, but a causal role for Nosema in queen-cell losses has not been demonstrated. Unexplained sealed-cell losses in a queen-rearing operation warrant Nosema microscopy on the cell-building colony, not just a review of grafting practice.

11.18 Self-Check Questions

- Explain the mechanism by which Varroa converts a covert DWV infection into an overt one, specifically addressing what happens differently when the mite feeds on a pupa compared to oral transmission of the virus.

- A queen-rearing operation is losing 30% of its sealed queen cells with no obvious reason. The cells die after capping with darkened cell walls. What virus is the most likely agent, what associated colony-level condition is worth assessing, and what test confirms that condition?
- Distinguish the two clinical syndromes of Chronic Bee Paralysis Virus. For each, name the most likely misdiagnosis and explain what finding would help separate CBPV from that alternative.
- A colony is examined in April and found to have brown fecal streaks inside the hive and across the top bars. The beekeeper concludes it has *Nosema apis* and decides to treat. What information is missing, and what must be done before treatment is justified?
- Explain why *Vairimorpha ceranae* is more difficult to detect by field observation than *Vairimorpha apis*, and describe the one procedure that can confirm its presence.
- A dead colony is found in late January with a small cluster of dead bees between two frames, heads extended into empty cells, and three full frames of capped honey on either side. Identify the proximate cause of death and the underlying cause you should investigate. What post-mortem findings would support the underlying cause?
- A beekeeper treats with amitraz strips in October and does not recheck mite levels. In January she finds 20-30 bees with deformed wings among the dead in front of each hive. What does this most likely indicate, and what should the response include?
- Colony Collapse Disorder as defined in the primary literature is characterized by which combination of findings? Why does delayed robbing of intact stores matter to the case definition?
- Explain why fumagillin treatment of a Nosema-infected colony must be accompanied by comb management to achieve durable control, and state what happens if the comb reservoir is not addressed.
- A beekeeper in a well-managed yard observes bees in front of three hives in July trembling and unable to fly. The following morning there are piles of dead bees in front of those hives. Name at least four conditions that could produce this picture and describe the first practical steps to narrow the differential.
- What is parasitic mite syndrome, and why is it a clinically useful concept even though it is not a distinct etiological entity?

11.19 Self-Check Answers

- Oral transmission of DWV requires the virus to pass through the gut epithelium, which acts as a partial barrier and limits the viral titer that reaches the hemolymph. When Varroa feeds on a pupa, it injects virus directly into the hemolymph, bypassing the gut barrier entirely and delivering virus at a site where it immediately contacts the fat body and developing wing tissue. Simultaneously, the nutrient drain of mite feeding, which in the pupa is mainly hemolymph, leaves a smaller, weaker fat body and reduces the bee's immune capacity to contain replication. The combined effect is a many-fold increase in circulating virus titer, which pushes the infection from subclinical to clinically damaging – producing the wing deformity by interfering with wing

disc development in the pupa. Mite feeding during the pupal stage is the highest-risk exposure window because developmental processes are most sensitive to disruption.

- The most likely virus is Black Queen Cell Virus (BQCV). The concurrent condition to assess is Nosema infection in the nurse-bee source colony, since BQCV has a documented association with Nosema. The confirmation procedure is microscopy of bees from the cell-building colony: macerate 30-60 forager or entrance bees in water at 1 mL per bee, apply a drop to a slide, and examine at 400x magnification for the characteristic oval refractile Nosema spores. A spore count using a hemocytometer quantifies the level. Species identification requires PCR, but for operational purposes, confirming significant Nosema levels (above roughly 1 million spores per bee) is sufficient to direct management.

- CBPV Type 1 produces trembling, bloated, flightless adult bees with dead bees accumulating outside the hive; the most likely misdiagnosis is acute pesticide poisoning, which also causes trembling, flightless bees. Pesticide kills tend to be sudden in onset, affect all colonies simultaneously after a nearby application, and often include extended proboscises in the dead; CBPV develops more gradually and is associated with crowded conditions. CBPV Type 2 produces hairless, dark, shiny bees being rejected by guards; the most likely misdiagnosis is aging forager bees or pesticide darkening. The distinction: CBPV Type 2 produces a cohort of affected bees of apparently working age, with active guard harassment as a clinical sign, in an overcrowded colony, while normal forager hair loss is individual and not associated with rejection behavior.

- Missing information: the beekeeper does not know whether the fecal streaking is caused by Nosema, by fermented or inappropriate stores, by prolonged winter confinement, or by another cause. Required action before treatment: collect 30-60 foragers or entrance bees, macerate in water, and examine under a compound microscope at 400x for Nosema spores. If spores are found, quantify by hemocytometer. Treatment without confirmed Nosema diagnosis is unjustified because the cause may be non-infectious, because the relevant species (V. ceranae vs. V. apis) determines prognosis, and because fumagillin — though available over the counter — should never be applied without a confirmed diagnosis, since dosing an antibiotic-class product for a condition that may not be Nosema at all wastes the treatment and delays finding the actual cause.

- *V. ceranae* produces little to no dysentery, so the classic field sign of fecal spotting is absent or minimal in most infected colonies. The hive exterior and interior may be clean while the colony carries a heavy infection of millions of spores per bee. *V. apis* classically produces visible spring dysentery after winter confinement, making it easier to suspect by observation. The one confirming procedure for either species is microscopy of macerated bee abdomens: collect 30-60 foragers, macerate in water, apply to a slide, and examine at 400x for refractile oval spores. Species differentiation requires PCR, since spore morphology is not reliable enough by light microscopy alone.

- Proximate cause: isolation starvation – the cluster consumed the stores around it, shrank to a size that could not cross cold comb to reach adjacent stores, and starved with honey present. Underlying cause to investigate: Varroa and associated DWV damage to the autumn bee cohort that produced a small overwintering cluster of physiologically compromised bees. Post-mortem findings supporting the mite-virus cause: white specks (mite fecal deposits) on the upper inner walls of vacated brood cells; deformed-winged bees among the dead cluster; a brood pattern

from autumn frames showing irregular cells if comb was retained; and the small cluster size itself, inconsistent with the stored honey supply, which suggests the population declined through autumn before winter set in.

- The most likely explanation is that amitraz treatment failed due to resistance – amitraz resistance is widespread, and all 39 mites genotyped in the 2024-25 collapse study carried the resistance mutation – and mites continued reproducing through autumn and into winter, with DWV accumulating in the overwintering bees. The deformed-wing bees are those that eclose from cells with high mite loads. Response: run an emergency mite wash on any surviving colonies immediately; switch to a non-amitraz mode of action suited to winter conditions (oxalic acid in the broodless period; formic acid only within its label temperature range) for any surviving colony requiring treatment; implement mandatory post-treatment mite counts to verify efficacy; and investigate whether the entire operation's mite population should be tested for resistance.

- CCD is characterized by: rapid disappearance of the adult bee population; the presence of a laying queen; capped brood remaining in the hive; honey and pollen stores present; very few or no dead adult bees inside the hive or near the entrance; and stores not immediately robbed by neighboring colonies or infested by wax moths or small hive beetles despite being undefended. The delayed robbing of intact stores matters because an undefended colony with full honey supers normally draws robbers within hours. The failure of robbing behavior to start promptly was taken as evidence that something in the affected colony's chemistry or odor deterred robber bees and pests – an observation that distinguished the syndrome from ordinary colony mortality.

- Fumagillin works by inhibiting microsporidian replication inside living bee cells. It reduces the active spore-producing phase of the infection within bees that consume it, lowering the spore count in the adult population during treatment. However, it does not penetrate wax comb and does not kill spores already deposited in cells by previously infected bees. Spores on comb are stable for months to years. When treatment ends and new bees emerge and begin consuming stored pollen or honey from contaminated comb, or when bees groom cells containing spores, the infection reestablishes. A colony treated with fumagillin without comb management typically shows declining spore counts during treatment and then returns to high counts within weeks of treatment cessation. Durable control requires comb rotation, replacement, or decontamination alongside any pharmacological intervention.

- Differential diagnosis for summer adult bee mortality with trembling: acute pesticide poisoning (most common cause of sudden summer adult mortality, especially after nearby agricultural applications); Chronic Bee Paralysis Virus Type 1 (trembling, bloated, crawling bees, associated with crowding); spiroplasmosis (*Spiroplasma apis* or related species), a bacterial hemolymph pathogen that causes seasonal adult mortality with similar crawling symptoms; heavy Nosema compounded by concurrent stressors; and robbing-induced fighting mortality, if colonies nearby are collapsing. First steps: examine dying bees carefully for extended proboscises (pesticide), bloated abdomens with spread wings (CBPV), or other distinguishing features; determine how many colonies are affected and whether apiaries in the surrounding area show the same problem; find out what has been sprayed in the surrounding area and when; collect several hundred freshly dead bees per affected hive, label with collection time, and freeze immediately for laboratory analysis; photograph the scene; contact the state apiary inspector; if pesticide exposure is suspected, contact the state lead pesticide regulatory agency.

- Parasitic mite syndrome is a descriptive clinical label for the complex of brood and adult pathology produced by a heavy Varroa infestation and its associated viruses, particularly DWV. It is not a discrete disease with a single pathogen, single mechanism, or single treatment; it is a pattern that emerges from the combined effects of mite feeding, fat body damage, viral amplification, and secondary infections. Its clinical value is that it names a recognizable pattern – scattered brood, discolored and dying larvae in varied positions, crawling adults with deformed wings, rapid population decline – that fits no single classical disease description and could otherwise prompt an unproductive search for a novel pathogen. Recognizing the pattern directs the beekeeper to run a mite count and apply treatment, which is the correct and productive response. The ability to name and explain parasitic mite syndrome signals that a candidate understands Varroa not just as a mite but as the primary driver of viral and secondary bacterial disease in modern colonies.

11.20 Further Reading

- de Miranda JR & Genersch E. "Deformed wing virus." *Journal of Invertebrate Pathology* 103:S48-S61 (2010). The foundational review on DWV biology, strains, pathology, and Varroa vectoring. Required reading.

- Lamas ZS, Rinkevich FD, Garavito A, et al. "Viruses and vectors tied to honey bee colony losses." *PLOS Pathogens* 22(2): e1013939, 23 February 2026. The 2024-25 US loss event, amitraz resistance, ABPV and DWV prevalence data cited in this chapter.

- Fries I. "Nosema ceranae in European honey bees (*Apis mellifera*)." *Journal of Invertebrate Pathology* 103:S73-S79 (2010). Comprehensive review of *ceranae* biology, spread, and pathology.

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- Bailey L & Ball BV. *Honey Bee Pathology*, 2nd ed. Academic Press, 1991. The classic reference on viruses and microsporidians; CBPV, sacbrood, and BQCV coverage remains authoritative.

- Honey Bee Health Coalition. *Tools for Varroa Management*, 9th edition, June 2026. Current guidance on mite thresholds, treatment options, and post-treatment verification; essential for the virus-through-Varroa connection.

- Cantwell GE. "Standard methods for counting Nosema spores." *American Bee Journal* 110:222-223 (1970). Still the standard reference for hemocytometer-based spore counting methodology.

- vanEngelsdorp D, Evans JD, Saegerman C, et al. "Colony Collapse Disorder: a descriptive study." *PLOS ONE* 4:e6481 (2009). Established the case definition and described the diagnostic criteria for CCD.

- Shimanuki H & Knox DA. *Diagnosis of Honey Bee Diseases*. USDA Agriculture Handbook 690, 2000. Practical diagnostic guidance for field and laboratory use; covers Nosema, viruses, and adult disorders.

- Ramsey SD, Ochoa R, Bauchan G, et al. "Varroa destructor feeds primarily on honey bee fat body tissue and not hemolymph." *Proceedings of the National Academy of Sciences* 116(5):1792-1801

(2019). Established the fat body feeding mechanism, reframing how Varroa damage suppresses immunity and amplifies viral titer.

- University of Florida IFAS Extension. Publications on honey bee disease diagnosis and Nosema management (various authors and years). EDIS database, freely available. Particularly useful for diagnostic procedures.
- NC State Extension Apiculture. Publications on colony health and disease management; relevant regional perspectives, particularly for the southeastern US.
- Huang W-F, Solter LF, Yau PM & Imai BS. “Nosema ceranae escapes fumagillin control in honey bees.” *PLOS Pathogens* 9:e1003185 (2013). Showed that as fumagillin degrades or dilutes in the hive, *N. ceranae* spore production can rebound above untreated levels (escape from suppression, not demonstrated genetic resistance), questioning the standard dosing protocol.

Chapter 12. Varroa & Tracheal Mites

Covers exam questions Q214-Q238.

12.1 Orientation

Varroa destructor is the single greatest threat facing managed *Apis mellifera* colonies worldwide, and it is the subject on which more master-level candidates struggle than any other. The reason is not that the facts are obscure – most experienced beekeepers know that they should treat at two to three mites per hundred bees, and many know the names of the registered products. The reason candidates struggle is that the exam at this level tests the mechanism behind every fact, and the mechanisms are interlocking in ways that catch people who have learned the numbers without learning why those numbers are what they are.

Three ideas organize everything else in this chapter. First, *Varroa* is simultaneously a feeding parasite and a virus delivery system, and its harm as a vector far exceeds its harm as a parasite – which is why intervention thresholds are measured in single-digit percentages rather than tens of percent. Second, the timing of infestation relative to the bee's developmental stage determines the severity of damage, and that timing is why a seemingly modest mite count in late summer is a far more serious situation than the same count in spring. Third, resistance to the most widely used synthetic acaricide has now reached levels that make post-treatment verification not just good practice but the essential control mechanism of the entire management system.

A master-level candidate must also understand the practical ecology of the problem: mites do not stay inside one colony, populations grow faster than most beekeepers intuit, and a single neglected hive within flight range imposes real costs on every beekeeper within robbing distance. That scope – from molecular biology of resistance to apiary layout – is what this chapter covers.

12.2 Taxonomy and the Importance of the Reclassification

The mite that kills *Apis mellifera* colonies worldwide is *Varroa destructor*, not *Varroa jacobsoni*. The distinction was established by Anderson and Trueman in 2000 and carries more practical weight than a nomenclature change usually does. Before the reclassification, *V. jacobsoni* was understood as a broadly distributed parasite of Asian honey bees that had made an ecologically catastrophic host jump to European honey bees sometime in the twentieth century. What Anderson and Trueman showed through genetic analysis is that the populations reproducing successfully on *Apis mellifera* are a taxonomically distinct species, and within that species, only two haplotypes – the Korean and Japanese/Thai – are responsible for virtually all infestations of *A. mellifera* worldwide.

The practical consequence is the narrow genetic base of the invading population. A worldwide infestation descended from what amounts to a handful of founding lineages means that *V. destructor* behaves with remarkable consistency everywhere it has spread: its reproductive biology, its preferences, its response to treatments, and the resistance mutations that have emerged are largely the same whether the colony is in the Gulf coastal lowlands or in northern Europe. That consistency is useful

for a beekeeper seeking guidance from the literature, but it also means that a resistance mutation that emerges anywhere in the world is worth tracking globally.

V. jacobsoni, the species that was originally described and remains largely confined to *Apis cerana*, is a comparatively minor pest on its natural host. The reason is co-evolution: *A. cerana* populations have lived with this mite for long enough to develop behavioral defenses, particularly hygienic removal or entombing of infested cells and intense grooming - and in *A. cerana* the mite can reproduce only in drone brood, which is present for part of the year. *A. mellifera* carries none of those defenses, which is why it was devastated by a host-adapted parasite in the span of decades.

The reclassification also matters for biosecurity thinking. The world still contains *V. jacobsoni* haplotypes that have not successfully colonized *A. mellifera*, plus other *Varroa* species on other *Apis* hosts. A host-range expansion by any of those populations would present a novel infestation for which no management infrastructure exists. That concern is not theoretical: it is one of the reasons interceptions of exotic *Apis* swarms are taken seriously by quarantine authorities.

12.3 The Reproductive Cycle: Mechanics and Management Leverage Points

Understanding exactly what *Varroa* does inside a brood cell is not an academic exercise. Every major management strategy – brood interruption, drone brood trapping, timing of oxalic acid application – is a direct manipulation of this biology, and a beekeeper who understands the cycle can reason out what a technique will and will not accomplish rather than following instructions by rote.

12.3.1 The Phoretic Phase

Between reproductive cycles, and through broodless periods, *V. destructor* rides on adult bees in what is called the phoretic (or dispersal) phase, concealed in the inter-segmental membranes of the bee's abdomen where grooming is least effective. During this phase the mite is not simply waiting: it feeds actively on the bee's fat body, a diffuse tissue distributed through the abdomen that is central to immunity, vitellogenin production, detoxification, and the energy storage that sustains winter bees. The 2019 work of Ramsey and colleagues revised the long-standing understanding that mites fed primarily on hemolymph; fluorescent staining and electron microscopy showed the fat body is the primary feeding site in mites on adult bees (on pupae it is different: a 2024 study by Han and colleagues found that mites reproducing in the sealed cell feed mainly on hemolymph, so the diet depends on the host's life stage). This revision is not merely academic – it supplies a mechanism for the physiological damage that hemolymph loss alone explained poorly, including impaired immune function, reduced vitellogenin, shorter adult lifespan, and compromised overwintering capacity.

Phoretic mites have a strong behavioral preference for nurse bees, the young adult bees working within the brood nest. This preference is the reason that alcohol wash samples should be taken from brood frames – a sample of foragers returning from the field will underestimate infestation because foragers carry proportionally fewer mites.

12.3.2 Cell Entry and Founding Behavior

The foundress mite enters a brood cell in the hours just before it is capped, typically when the larva is at the appropriate developmental stage to trigger the mite's entry behavior. She conceals herself beneath the larval food at the bottom of the cell, where she is largely protected until capping seals her in. She begins feeding on the developing pupa within the sealed cell and lays her first egg about 60 to 70 hours after capping.

12.3.3 Egg Sequence and Sibling Mating

The foundress lays her first egg about 60 to 70 hours - roughly three days - after capping. That first egg is unfertilized and develops into a haploid male. Subsequent eggs, laid at intervals of approximately thirty hours, are fertilized and develop into females. The male matures first – he is smaller and has a faster developmental time – and he mates with his sisters within the sealed cell. This is obligate sibling mating: there is no opportunity for outbreeding, and the male never leaves the cell. After mating is complete, the male and any females that did not reach maturity in time die within the cell. Only mated females that have completed development leave the cell when the adult bee emerges. Unmated females are reproductively dead ends.

The practical consequence of sibling mating is that a hygienic colony that removes a single infested pupa eliminates the entire reproductive family. The male and all immature sisters die with the pupa, and the foundress loses that reproductive cycle even if she escapes. This is one reason hygienic behavior is a genuine resistance mechanism rather than a cosmetic behavioral trait.

12.3.4 Worker Versus Drone Brood: Why the Preference Matters

Varroa shows a strong preference for drone brood, infesting drone cells at roughly eight to ten times the rate of worker cells when both are available. The reason is simple: the capped period for drone brood is about two to three days longer than for worker brood (roughly 14 days against 12; total development is twenty-four days against twenty-one). Each additional day of capping allows the foundress to lay another egg and allows another daughter to reach maturity and mate. In worker brood, the reproductive output averages approximately 1.45 mature mated daughters per foundress, because the capped period is tight; in drone brood, the output per cell is substantially higher.

The management applications flow directly from this. Drone brood trapping – the insertion of a frame of drone-sized foundation or empty drone comb to act as a reproductive sink – exploits the mite's preference by concentrating reproduction in a compartment the beekeeper can then remove. The absolute requirement is timing: the drone frame must be removed and the brood destroyed before emergence, because a drone frame allowed to emerge is a mite amplifier, releasing all the mites that reproduced within it back into the colony at once. The technique requires a strict schedule and ruthless follow-through.

12.4 How Varroa Harms Bees: The Virus Problem

The fat-body feeding described above is damaging, but it is not the primary mechanism by which *V. destructor* kills colonies. The primary mechanism is virus delivery. The mite acts as what immunologists would call a biological vector: it not only transmits deformed wing virus and other pathogens but does

so in a way that bypasses the bee's primary defenses and actively suppresses the immune response at the delivery site.

When *Varroa* feeds through the bee's cuticle, it creates a wound through which it injects salivary compounds that suppress local immunity. This immune suppression at the feeding site appears to allow virus particles to enter the hemocoel – the body cavity – directly, rather than passing through the gut, where the bee's immune system is most effective at neutralizing ingested pathogens. Virus inoculated this way achieves titers in infected bees orders of magnitude higher than the same virus delivered orally. The mite-feeding bee becomes systemically infected, not merely exposed.

Deformed wing virus (DWV) is the most consequential pathogen in this system. Before *Varroa* arrived in a given region, DWV was present in most bee populations but caused minimal disease because titers remained low through oral transmission alone. *Varroa* transformed DWV from a background pathogen into the leading cause of bee developmental and adult mortality. DWV-B, a distinct variant, is now the dominant strain in most of the world, having displaced DWV-A in regions where *Varroa* has been established for decades. A 2026 study by Lamas, Rinkevich, Garavito and colleagues found DWV-B present in 100 percent of symptomatic bees examined, and DWV-A in 78 percent of the pooled colony samples; the authors describe mite-associated virus levels, especially ABPV, as unusually high compared with earlier national surveys.

The same Lamas et al. 2026 study found acute bee paralysis virus (ABPV) in 72 percent of screened colonies, also at levels above prior surveys. ABPV, like DWV, is transmitted far more efficiently by *Varroa* feeding than by oral routes, and high titers are associated with winter collapse. Kashmir bee virus (KBV) and Israeli acute paralysis virus (IAPV) are also vectored by the mite, though they are less universally prevalent.

The downstream effects of DWV infection are substantial. Bees that develop as pupae under heavy mite infestation emerge with shorter lifespans, impaired learning and navigation ability, reduced body mass, and in severe cases the truncated abdomens and vestigial wings that give the virus its name. These bees look normal at emergence – the deformed wing phenotype appears only in severely infected individuals – but they fail early, producing a colony that loses population faster than the queen can replace it. The colony collapses not because mites outnumber healthy bees but because the bees being produced are physiologically compromised.

This is the single most important conceptual point in the chapter: a mite count is not just a measure of parasitic burden. It is an index of viral disease risk. A colony with four mites per hundred bees is not merely a colony carrying four parasites per hundred adults – it is a colony in which the conditions for systemic DWV epidemics in developing brood are already well established. The intervention thresholds discussed in the next section are calibrated to this reality.

12.5 Monitoring: Methods, Sample Size, and When to Sample

Quantitative monitoring is not optional at the master level. A beekeeper who treats on a calendar rather than on measured thresholds both over-treats (increasing chemical selection pressure and wax

contamination) and under-treats (missing genuine need when the calendar says it is not time). Monitoring means counting mites and expressing the result as mites per hundred bees.

12.5.1 Alcohol Wash: The Reference Method

The standard reference method is the alcohol wash, described in the Honey Bee Health Coalition's *Tools for Varroa Management* (9th edition, released June 2026) and in the COLOSS BeeBook monitoring protocol. The procedure is straightforward: take a sample of approximately 300 bees (half a cup by volume) from a brood frame, ensuring the queen is not present. Nurse bees – young bees working within the brood nest – carry more phoretic mites than foragers, so sampling from a brood frame rather than a super or an entrance gives a more accurate representation of the colony's mite load. Immerse the sample in isopropyl alcohol, agitate to dislodge mites, and count the mites in the wash. Divide by total bees to get percentage.

Three hundred bees is the target because it provides enough statistical resolution to be meaningful while remaining practical. A sample of 100 bees is statistically noisier; a sample of 500 bees is more accurate but the added precision is rarely necessary for management decisions. The method is lethal to the sampled bees, which is the primary objection practitioners raise, but it is the most accurate available field method.

12.5.2 Sugar Roll: Non-Lethal but Less Accurate

The sugar roll is a non-lethal alternative that uses powdered sugar to dislodge mites, which are then counted on a white surface. Its advantage is that the sampled bees survive; its disadvantage is that it recovers a smaller fraction of the mites actually present on the bees, and that fraction varies with humidity. In humid conditions, powdered sugar clumps rather than coating individual bees, and mites adhere to the wet sugar rather than falling free. Under southeastern US summer conditions, a sugar roll regularly underestimates infestation relative to a paired alcohol wash. For management decisions, particularly during the critical late-summer window, underestimation is a serious failure mode: a count that appears acceptable may be hiding an actionable infestation.

12.5.3 Sticky Board Natural Mite Drop: For Trends, Not Thresholds

A screened bottom board with a sticky insert captures mites that fall naturally from adult bees over a defined period, usually 24 hours. Natural mite drop reflects the phoretic mite population in a general way, but it is confounded by colony size, brood status, ambient temperature, and the health of the colony itself (dying colonies drop mites as bees fall off surfaces). There is no validated natural-drop threshold, so no particular 24-hour count should be treated as a trigger for action, unlike an alcohol wash percentage; a noticeable drop is a cue to follow up with an alcohol wash. Sticky boards are most useful for trend monitoring – watching whether a number is rising or falling between washes – and for detecting the presence of the mite when a beekeeper suspects infestation. They are not appropriate as the sole basis for a treatment decision.

12.5.4 When to Monitor

Minimum monitoring frequency is three times per year: late winter or early spring as brood rearing begins, mid-season (typically after the spring flow), and late summer, which is the decisive monitoring

point of the year. The temptation, particularly for beekeepers who find a low count in spring, is to assume that condition will persist. It will not. Mite populations grow multiplicatively with each brood cycle, not linearly. A colony starting spring at 0.5 percent infestation and experiencing unchecked reproduction through a long brood-rearing season can reach economically damaging levels by midsummer. The southeastern US presents a particular challenge here because the brood-rearing season is substantially longer than in northern regions – in some coastal and Gulf Coast areas, colonies barely have a true broodless period even in winter – which means more mite generations per year and faster population growth from any starting baseline.

The practical rule is this: a spring count is not a prediction. It is a starting point on a rising curve, and the slope of that curve depends on colony size, presence of drone brood, available worker brood, and whether hygienic behavior is present in the colony's genetics.

12.6 Thresholds: What the Numbers Mean and Why the Season Changes Them

The Honey Bee Health Coalition's *Tools for Varroa Management*, 9th edition (June 2026), establishes the current standard thresholds. Its action levels are set by colony phase: prompt control at 1 percent (1 mite per 100 bees) while the colony is dormant and during spring population increase, and at 2 percent at peak population and during the late-summer and autumn decline. Some older guidance, and some examination items, quote 2 to 3 percent for late summer; the current HBHC figure is 2 percent, and acting promptly at that level rather than waiting for a confirmatory recount is the safer course.

Candidates who have memorized these numbers but not the mechanism behind them will fail any item that asks why the late-summer count carries so much weight. The answer is not simply that there are more mites in the colony then (though there often are). It has to do with the identity of the bees being reared at that time. Bees produced in late summer and early autumn – roughly late August into October – are the cohort that must survive through the winter and into the following spring. They are physiologically distinct from summer bees: they accumulate more fat body, produce more vitellogenin, and are capable of living six months or more if they reach adulthood in good condition. The colony depends on this cohort entirely. If those bees develop as pupae under heavy mite and virus pressure, they emerge already damaged – with shorter expected lifespans, impaired immunity, and reduced fat stores. The colony enters winter already depleted of its most important asset, and that damage cannot be undone after the bees are adults.

The late-summer count therefore carries more weight, not because more mites are present but because each mite carries more consequence. A mite damaging a July forager costs the colony that bee's foraging contribution. A mite damaging a September nurse bee costs the colony a potential six-month winter survivor. Treatment at 2 percent in late summer is an investment in the survival of bees that have not yet been born.

This reasoning also explains why the post-treatment count is a non-negotiable step, not a follow-up formality. If a treatment was applied in late August and did not work, the beekeeper may discover this only in November or December when the colony collapses – after the entire winter cohort was reared

under the mite load that should have been controlled. The window for correction closes when the last winter bees are capped. After that, monitoring can detect the damage but cannot undo it.

12.6.1 Recognizing Varroa Collapse Post-Mortem

When a colony is found dead and *Varroa* is suspected, certain findings at post-mortem examination are diagnostic. Bees with shortened abdomens and vestigial or absent wings among the dead population point to high DWV titers. Mites may be visible in uncapped cells, but the mites themselves are often gone or few in a colony that has fully collapsed. More diagnostically useful are the white deposits visible on the upper walls of brood cells – guanine, the nitrogenous waste of mite reproduction – which persist after the mites and bees are long gone and provide evidence of heavy mite reproductive activity during the autumn brood cycle. A colony found dead with its honey stores largely intact died for lack of bees, not lack of food, which is the classic *Varroa*-associated collapse signature: the cluster ran out of bees before it ran out of winter provisions.

12.7 The Treatment Arsenal: Mechanisms, Constraints, and Registered Products

Treatment decisions require knowing not just which products exist but what mechanism each uses, what temperatures constrain it, and what brood status makes it effective or ineffective. Products that share a mechanism share a resistance pathway, which determines how rotation must be structured.

12.7.1 Oxalic Acid

Oxalic acid is an organic acid naturally present in many plants and, in small quantities, in honey itself. Four products are currently registered for use in the United States: **Api-Bioxal** (powder for dribble, spray or vaporization); **Api-Bioxal RTU** (a ready-to-use solution); **EZ-OX** tablets; and **VarroxSan**, extended-release glycerin-impregnated strips registered by EPA in December 2023 and the only extended-release oxalic acid product registered in the US as of this writing.

Oxalic acid does not penetrate the wax cappings of sealed brood cells. This is its principal limitation: in a colony with brood, the mites inside sealed cells are untouched by dribble or sublimation applications. Efficacy against phoretic mites on adult bees is high – typically above 90 percent for a single properly applied treatment – but in a colony with a full brood complement, the majority of the mite population may be in sealed cells at any given time. A single application at such a time kills a fraction of the population, and the fraction that survives is exactly the fraction about to emerge already mated and reproductively capable.

The two strategies for working around this limitation are well-established. The first is to treat during a genuine broodless period. In the southeastern US, this window is short and uncertain – a warm spell can restart brood rearing in December or January – so broodlessness must be confirmed by inspection rather than assumed from the calendar. The second strategy is to use the extended-release strip formulation, which keeps active compound in the hive across a full brood cycle (the VarroxSan label specifies 42 to 56 days), so that bees walking over the strips pick up and spread oxalic acid by contact, reaching successive cohorts of mites as they emerge from cells with their host bees. University field

trials conducted between 2021 and 2023 found VarroxSan effective in fall and early summer applications with no significant oxalic acid residues in harvested honey.

Application by sublimation requires the operator to use appropriate respiratory protection: oxalic acid vapor is toxic to respiratory tissue, and the vapor does not respect hive-body boundaries when a sublimator is in use. This is a label requirement, not an optional precaution.

Oxalic acid's mode of action against mites is incompletely understood but is believed to involve contact toxicity and possibly interference with cuticle integrity. It is classified as an organic acid, not a synthetic acaricide, and it is distinct in its mechanism from every other registered treatment – which is why it is a cornerstone of rotation strategies.

12.7.2 Formic Acid

Formic acid, sold in the United States as FORMIC PRO (the successor to the older Mite Away Quick Strips, MAQS, which the HBHC 9th edition no longer lists), occupies a unique position among *Varroa* treatments because it is the only widely available chemical that kills mites inside sealed brood cells. As a vapor, formic acid penetrates the wax cappings that seal developing pupae and reaches mites in the reproductive phase. This makes it valuable in precisely the situation where oxalic acid is least effective: a colony with a full brood nest.

The corresponding cost is a narrow safety margin. Formic acid at therapeutic concentrations is also toxic to developing brood and, at the high end of the temperature range, to queens. The label specifies a temperature window: apply only when daytime highs are between 50 and 85 degrees F (Formic Pro label). The lower limit exists because efficacy depends on vapor generation, which requires heat. The upper limit exists because at high temperatures, vapor concentration inside the hive rises to levels that kill uncapped brood and can drive queens into the cluster or cause them to cease laying.

In the southeastern US, the practical challenge is the upper temperature limit. Summer highs frequently exceed 90 degrees F – and inside a sun-exposed hive box, the internal temperature can be well above ambient. The useful application windows for formic acid in the warmer portions of the region are typically spring (before consistent high heat) and autumn (after sustained heat breaks). A beekeeper attempting a formic acid treatment in midsummer in a Gulf coastal climate is likely to violate the upper temperature limit on at least some days of the treatment period.

12.7.3 Amitraz

Amitraz (registered in the United States as Apivar and Amiflex) is a synthetic acaricide that acts on the mite's octopamine receptors, mimicking the mite's natural neurotransmitter in a way that disrupts nervous system function. It is lipophilic – readily dissolving in and concentrating in fats – but the parent compound breaks down quickly in the hive, so amitraz is much less persistent in wax than the older synthetics (tau-fluvalinate and coumaphos); some breakdown products remain. Apivar works by contact: bees walking across the strips pick up amitraz and spread it through the colony. Efficacy falls in cool weather because the cluster contracts and fewer bees contact the strips, which is why the strips must hang within the cluster in the brood area and be moved if the cluster shifts away from them.

Amitraz must not be applied when honey supers are present: the label prohibits it, and residues can reach honey.

Amitraz resistance has been documented since the 1990s in some regions and has been present at significant frequency in many US populations for over a decade. The 2026 study by Lamas, Rinkevich, Garavito and colleagues brings this from a worrying trend to a current crisis. The researchers screened mites from 18 colonies across five operations that had all been relying on amitraz as their primary control. Of 39 mites screened for the resistance mutation, 100 percent carried Y215H – a substitution at position 215 in the Octβ2R octopamine receptor gene in which tyrosine is replaced by histidine, altering the receptor structure so that amitraz no longer binds effectively. Earlier regional surveys had found this mutation in approximately 66 percent of screened mites; the jump to 100 percent in operations with heavy amitraz reliance represents exactly the selection dynamics that resistance theory predicts.

The management implication is direct: a beekeeper who treats with amitraz and does not follow up with a post-treatment mite count may be running an uncontrolled mite population while believing the colony is protected. Post-treatment verification is no longer optional practice – it is the mechanism by which resistance is caught before it causes colony loss.

12.7.4 Thymol

Thymol-based products – Apiguard (a gel formulation releasing thymol vapor) and ApiLifeVar (a thymol-impregnated pad) – act through vapor and contact. They are effective at temperatures above roughly 59 to 65 degrees F but efficacy falls sharply in cool conditions because vapor generation depends on heat. At the high end of the temperature range, thymol can cause a temporary reduction in queen laying and brood removal, which alarms beekeepers encountering it for the first time, and honey tainting is why the label prohibits use when supers are present.

In the southeastern US, thymol-based products face a seasonal compression from both ends. The useful window is bounded below by the temperature at which they work and above by the temperature at which they harm brood and queens, and summer highs in much of the region regularly exceed that upper bound. Thymol is most practically deployed in spring or early autumn in the warmer parts of the region.

12.7.5 Coumaphos

Coumaphos (CheckMite+) is an organophosphate synthetic acaricide that acts by inhibiting acetylcholinesterase in the mite's nervous system. It is highly lipophilic, accumulates extensively in beeswax, and has documented resistance populations worldwide. Coumaphos is rarely recommended as a first-line treatment today. Its inclusion in the chapter is necessary because it is a registered product, because resistance to it represents a real example of resistance selection in mite populations, and because the organophosphate class is meaningfully different in mode of action from the other options – which matters for understanding what constitutes a genuine rotation.

12.7.6 What Does Not Qualify as Mite Control

The master-level exam specifically tests awareness of the difference between approaches that have some effect on mite populations and approaches that can control those populations. Screened bottom

boards allow natural mite fall to leave the colony and provide modest reduction of phoretic mite load – controlled trials consistently show small reductions, typically below 15 percent – plus useful contribution to hive ventilation and monitoring. They are not a stand-alone mite control.

Small-cell foundation, promoted in some beekeeping communities as reducing mite reproduction by altering cell geometry, has been evaluated in controlled trials and does not produce significant reductions in mite population growth. The hypothesis has been studied; the effect has not been confirmed.

Powdered sugar dusting removes some phoretic mites immediately after application by disrupting the mite's attachment, but it does not reach mites inside sealed cells, the effect is short-lived, and no published controlled trial has demonstrated population-level control. Presenting powdered sugar as a mite treatment to a new beekeeper is among the more harmful pieces of advice that circulates in the craft, because it creates false confidence.

12.8 Rotation of Modes of Action: What It Means and Why It Matters

Rotation is not alternating between two brand names or between products of the same chemical family. Rotation is the deliberate movement among products that act on different molecular targets in the mite, so that resistance to one product does not confer resistance to another.

The principal modes of action available:

Mode of Action	Product Class	Examples	Resistance Risk
Contact/vapor organic acid	Oxalic acid	Api-Bioxal, Api-Bioxal RTU, EZ-OX, VarroxSan	Low, no confirmed field resistance
Fumigant organic acid (cap-penetrating)	Formic acid	FORMIC PRO (successor to MAQS)	Low
Octopamine receptor agonist	Amitraz	Apivar, Amiflex	Documented; widespread
Monoterpenoid vapor/contact	Thymol	Apiguard, ApiLifeVar	Low
Acetylcholinesterase inhibitor	Organophosphate (coumaphos)	CheckMite+	Documented
Sodium channel modulator	Pyrethroid (tau-fluvalinate)	Apistan	Documented; widespread
Hop beta acids (contact)	Potassium salt of hop beta acids	HopGuard 3	Low; none confirmed
RNA interference	dsRNA	Norroa (active ingredient vadescana; registered September 2025)	New; none documented

Alternating two pyrethroids is not a meaningful rotation, because they share a target site and a resistance mechanism; amitraz (octopamine receptor) and coumaphos (acetylcholinesterase) are

genuinely different modes, although resistance to each has been documented. A rotation that moves from amitraz (octopamine agonist) to oxalic acid (organic acid contact) to formic acid (fumigant) represents three genuinely distinct mechanisms and gives selection pressure no consistent target. Two other products are also registered for Varroa control, and the HBHC 9th edition lists both as usable with honey supers on: l-glutamic acid strips (MBG2X5G, Mite Bee Gone LLC, registered March 2025) and sucrose octanoate esters (OrganiShield).

The principle behind resistance: resistance is selection, not learning. A small fraction of a mite population may carry heritable mutations affecting a treatment's target. When that treatment is applied repeatedly, susceptible mites die and resistant mites reproduce, gradually replacing the susceptible population. The mites do not learn to avoid the product; they are not made resistant by exposure; the product does not degrade in their bodies. The heritable trait was already there, at low frequency, and the treatment selected it. The management response follows directly: reduce selection pressure by rotating among different modes of action, treating only when thresholds indicate need (not by arbitrary calendar), and never using a subtherapeutic dose – a dose low enough to kill susceptible mites but not resistant ones is the most effective resistance-selection regime imaginable.

The observation that acaricides are not entirely selective between mites and bees is also relevant here. Both are arthropods, and the physiological difference between an arachnid and an insect, while real, does not create absolute safety margins. Every registered in-hive acaricide has some toxicity to bees at some dose. Selectivity is a matter of degree – differences in body size, cuticle permeability, nervous system organization, and behavioral exposure patterns create margins that allow therapeutic doses to kill mites while leaving bees largely intact. This is why label doses exist and why improvising a stronger concentration is both unsafe and unlawful.

12.9 Biotechnical Controls: Brood Interruption and Drone Trapping

Biotechnical controls manipulate the biology of the mite or the colony without the use of chemical treatments. They are more labor-intensive than chemical application, but they have several properties that chemical treatments lack: they select for nothing, they produce no wax contamination, and they are maximally effective when chemical treatments are least effective. Used in combination with chemical treatment, they reduce total chemical exposure and can catch mites that a chemical treatment misses.

12.9.1 Brood Interruption

The mechanism is simple: *Varroa* can reproduce only inside sealed brood cells. A colony with no sealed brood at all is a colony in which every mite is phoretic – on adult bees where it is accessible to a contact treatment like oxalic acid. A single well-timed oxalic acid application to a broodless colony can achieve efficacy above 95 percent, because the mite has no refuge.

Creating a broodless period deliberately requires either removing all sealed brood from the colony, caging the queen so that no new eggs are laid until the existing sealed brood has emerged, or making a split such that one portion is queenless while it rears an emergency queen. Cage duration should be about three weeks, and up to 24 days if drone brood is present: an egg laid just before caging becomes an adult worker 21 days later (a drone 24 days later), and until then some brood remains sealed. In

practice, allowing a day or two of margin is wise, since caging dates and brood ages in a real colony are not perfectly synchronized.

The cost of a brood break is lost production. The colony produces no new bees for the duration, and population declines during that period. Timing is therefore critical: a brood break timed immediately after the main nectar flow allows the beekeeper to exploit the break for mite control without sacrificing foraging capacity during the flow, and a post-flow brood break combined with requeening accomplishes two management goals at once.

In the southeastern US, a mid-summer brood break also offers a natural opportunity: many beekeepers split for swarm prevention or increase in spring, and the queenless half of a split experiences a natural break while rearing an emergency queen. That break is an ideal moment for oxalic acid application.

12.9.2 Drone Brood Trapping

Drone brood trapping converts the mite's preference for drone cells into a control mechanism. The principle: install a frame of drone-sized foundation or empty drone comb in the brood nest and let the colony fill it with drone brood. As that brood is capped, a disproportionate share of the colony's mite population enters those cells to reproduce. When the drone brood is sealed but before any drones emerge, remove the frame and destroy it – by freezing, by scraping, or by removing the brood cells entirely.

The removal must happen before emergence. Drone brood is sealed around day ten and emerges around day twenty-four from oviposition — a capped period of about fourteen days. A beekeeper who inserts a drone frame and removes it at day twenty-two has captured most of the mite reproduction. A beekeeper who inserts the frame and removes it at day twenty-six has amplified the mite population by releasing all those reproductive daughters back into the colony with the emerging drones. The technique fails through inattention, and that failure mode – a drone frame left too long – is one of the most instructive examples in beekeeping of how a technique designed as a control can become a liability.

Drone brood trapping is labor-intensive at the scale needed to make a meaningful dent in a population – a single frame removed every three to four weeks captures some mites but cannot by itself keep pace with a rapidly growing infestation. It is best used in combination with other controls and with monitoring to verify its contribution.

12.10 Distinguishing Treatment Failure from Reinvasion

A post-treatment mite count that fails to show expected reduction forces a diagnostic decision: did the treatment fail, or did mites reenter the colony from outside? The distinction determines the corrective action.

Treatment failure – the treatment was applied and did not reduce the mite population – can result from several categories of error. The first to check is methodology: was a valid pre-treatment count actually taken? Without a baseline, there is no comparison. The second category is application error: incorrect dose for colony size, wrong placement (a dribble applied to a cluster in one corner of a large hive, strips

installed in the super rather than in the brood box), wrong duration (strips removed early or left in so long that the product is exhausted), or product past its shelf life or heat-damaged in storage. The third category is environmental conditions: volatile treatments applied during temperatures outside the label range are ineffective or harmful. The fourth category is brood status: a treatment that does not penetrate cappings, applied to a colony with a full brood complement, leaves most of the mite population untouched. The fifth category, and only after these others are excluded, is resistance.

Reinvasion is distinguished from treatment failure by timing. A count taken promptly at the end of the treatment period – before sufficient time has elapsed for substantial immigration – reflects what the treatment achieved. If that count is low, the treatment worked. If the count then rises over subsequent weeks, immigration is the explanation. If the count at the end of the treatment period is still high, the treatment failed.

The post-treatment count is taken promptly at the end of the labeled treatment period: for a single oxalic acid dribble or vaporization, a few days after application; for strip products, at strip removal, not while they are still in place. Timing matters: a count taken mid-treatment reflects the treatment's ongoing action, not its final outcome, and a count taken weeks later mixes in mites that have reinvaded since.

The consequences of misdiagnosis are significant. If a beekeeper concludes resistance is present when the real problem was application error, they rotate to a different product for no reason, possibly losing an effective tool. If they conclude reinvasion is responsible when treatment actually failed, they accept a mite level that should have triggered retreatment.

12.11 The Mite Bomb: Apiary-Level and Area-Wide Risk

Varroa management is not a colony-level problem. It is an apiary-level and, in areas of high colony density, an area-wide problem. Mites move among colonies through two mechanisms: bees from a collapsing colony are robbed out by neighboring colonies, and their mites travel with the honey; and bees from high-infestation colonies drift into neighboring hives, carrying phoretic mites with them.

A colony that is collapsing under mite pressure often has frames of honey and undefended brood when its guard bee population begins to fail. Neighboring colonies detect this resource and exploit it through robbing. Bees returning from a robbing event carry phoretic mites home, and those mites immediately enter the brood nest of the new colony. A single heavily infested collapsing colony – what beekeepers call a mite bomb – can reinfest every hive within a few hundred meters within weeks.

This has two direct implications for management. First, when a colony shows signs of collapse (rapid population decline, abandoned brood, loss of defensive behavior at the entrance), the responsible action is to identify it, address it promptly by treatment or combination, and prevent it from being robbed out. Second, a single beekeeper managing their colonies impeccably cannot protect against mite bombs from neighboring untreated apiaries. This is the strongest argument for area-wide coordination: neighboring beekeepers who treat together and monitor together are each other's insurance against the reinvasion that good individual management cannot prevent alone.

Apiary layout also matters. Drift – the phenomenon by which bees returning from foraging enter the wrong hive – is amplified by long straight rows of identical equipment and by prevailing wind patterns that drive bees to the end of a row. Positioning hives in irregular arrangements, facing different directions, with distinctive landmarks at each entrance, reduces drift and its associated mite movement.

12.12 Tracheal Mites: The Internal Acarine Parasite

Acarapis woodi, the tracheal mite, is the other acarine parasite of adult honey bees and deserves mention in any comprehensive treatment of bee parasitology, though its current importance is far below that of *V. destructor*. Understanding the difference between the two is itself examinable material.

A. woodi is an internal parasite. It lives inside the prothoracic tracheae – the main air tubes of the thorax – and can spread through adjacent tracheae as an infestation grows severe. The mite enters through the first thoracic spiracle, the opening of the breathing tube on the front of the thorax, and it does so mainly in bees less than about four days old. The very young bee's spiracular sensilla are not yet fully developed and presumably do not yet produce the age-related chemical cues that deter adult tracheal mites from entering older bees. Beyond that window susceptibility falls sharply, and bees older than about nine days are rarely infested for the first time, though existing infestations continue to develop.

Diagnosis of tracheal mite infestation cannot be made by external inspection. The mites are microscopic and internal; a beekeeper cannot see them on the surface of bees during routine inspection. The external sign most associated with heavy infestation is disjointed wings – called K-wing because the hindwing rotates to sit at an angle that creates a K shape with the forewing – along with bees that crawl rather than fly, particularly in cool weather when the ability to thermoregulate through flight is compromised. These signs are suggestive but not specific: other conditions produce crawling and disjointed wings, and mild tracheal mite infestations may produce no obvious external signs at all. Definitive diagnosis requires dissection of the tracheae under a dissecting microscope, Healthy tracheae are creamy white and translucent; infested tracheae look cloudy or discolored, with dark blotches or lesions, and the mites and their eggs can be seen within the tracheal lumen under magnification.

A note on identification: two other *Acarapis* species, *A. externus* and *A. dorsalis*, live on the exterior of honey bees in the bee's hair and on its cuticle. Finding an *Acarapis* mite on a bee's surface proves nothing about tracheal mite status; *A. woodi* can only be confirmed by dissection of internal tissues.

12.12.1 Historical Control and a Transferable Principle

The registered treatment for tracheal mites in the United States was menthol, applied as loose crystals placed on the top of the hive. Menthol sublimes – it converts from solid directly to vapor – at temperatures in the approximate range of 60 to 80 degrees Fahrenheit, producing a vapor within the hive that is toxic to the mites. Because efficacy depends on maintaining a therapeutic vapor concentration inside the colony, temperature, placement, and ventilation are not incidental details – they are part of the dose. Too cool, and too little menthol sublimes; too hot, and too much sublimes too fast, potentially repelling bees or driving the cluster away from the treated area. At the high end of temperatures, the crystals were placed on the bottom board rather than atop the cluster to moderate the concentration reaching the bees. Menthol is no longer widely used, partly because *A. woodi* is a

much lesser problem than it was before widespread resistant stock, and partly because many beekeepers find management inconvenient.

Grease patties – mixtures of vegetable shortening and powdered sugar – were used as a companion or alternative control. The mechanism proposed is that the shortening interferes with the tracheal mite's ability to locate and transfer to young host bees, since the mites appear to use olfactory cues to find susceptible bees. The efficacy evidence is less solid than for menthol, but the patties are benign and some operations used them prophylactically.

The principle these treatments illustrate transfers directly to *Varroa* management: a volatile or vapor-phase treatment's efficacy is determined by the concentration it achieves within the hive, not merely by the quantity applied. Temperature range, placement, entrance configuration, and duration are part of the dose. Formic acid and thymol, used against *Varroa*, are subject to exactly the same constraints, which is why those products' labels specify temperature windows, placement locations, and treatment durations – and why those specifications are not optional.

12.12.2 Current Status of Tracheal Mites

Acarapis woodi is substantially less prominent today than it was in the 1980s and 1990s, for two reasons. First, stock bred for *Varroa* resistance often carries elevated resistance to tracheal mites as well, possibly because hygienic behavior and other colony-level responses to internal parasites overlap. Second, some *Varroa* treatments, particularly thymol-based products, appear to suppress tracheal mite populations as a side effect. The mite persists, and it can still cause meaningful losses in highly susceptible stock, but it no longer commands the same management attention it did before *Varroa* arrived. A beekeeper investigating unexplained spring dwindle in a colony with otherwise unremarkable health indicators should include tracheal mite dissection in the differential diagnosis, particularly if the colony was obtained from a source not selected for resistance.

12.13 Tropilaelaps: The Next Threat

No chapter on *Varroa* is complete without noting the parasite that most closely resembles it in biology and potential impact. *Tropilaelaps mercedesae* is a brood-parasitic mite native to *Apis dorsata*, the giant Asian honey bee, that has expanded its range well beyond tropical Asia: since 2021 it has been reported in western Russia, Georgia and Uzbekistan, and it has been reported as established in parts of Europe. It is not established in the United States as of 2026.

A 2026 report published in Frontiers in Insect Science documents the July 2025 interception of an *Apis dorsata* swarm carrying *T. mercedesae* on a cargo vessel inbound to the United States – the kind of interception that quarantine authorities are designed to catch but that occurs more frequently than the public record reflects. Detection of *Tropilaelaps* is more difficult than detection of *Varroa*, because the mite spends very little time on adult bees. On *A. mellifera* it has generally been found to survive only a few days on adult bees without brood, but that interception, of an A. dorsata swarm that had been without brood for at least 29 days, suggests it can persist for weeks on adult bees, and swarms have now been shown to carry it to new colonies. Work published in 2026 questions the sensitivity of monitoring methods adapted from *Varroa* practice: alcohol wash protocols designed to detect phoretic

Varroa capture very few *Tropilaelaps* because the phoretic load is a small fraction of the total population at any given time. Brood uncapping and examination of sealed cells, or methods adapted from bump or ether roll techniques for uncapped brood, are more sensitive.

The southeastern US presents an elevated risk profile for *Tropilaelaps* establishment if it were to arrive, because the region's long brood-rearing season – the same feature that makes *Varroa* management more demanding than in northern areas – would favor rapid population growth. *Tropilaelaps* depends on brood to reproduce and, on *A. mellifera*, generally survives only days without it; a region where colonies maintain brood through most of the year is a region where *Tropilaelaps* could sustain populations year-round.

12.14 An Integrated Annual Management Calendar

Integrated *Varroa* management is not a series of treatments – it is a system in which monitoring, treatment, biotechnical manipulation, and record-keeping reinforce one another across the full year. The following calendar describes best practice for a sideline-scale operation in the southeastern US. Exact timing will vary by latitude, elevation, and local forage, but the logic is consistent.

Late winter and early spring (January through March). As brood rearing begins, take a baseline alcohol wash from each colony. In the warmer portions of the region, mites and brood will already be present; farther north or at elevation in the southern Appalachian mountains, the brood-rearing restart may occur in February or March. If counts are at or above 1 percent (the HBHC 9th-edition action level for the dormant and population-increase phases), treat with a product appropriate for the conditions: oxalic acid strip or dribble works during this period if the colony is broodless or nearly so; formic acid may be applicable if daytime highs fall between 50 and 85 degrees F; strip treatments are an option if no supers are yet present.

Spring expansion (April through May). Make splits for swarm prevention and for increase. Each split contains some mites, and the queenless portion undergoes a natural brood break while rearing an emergency queen or accepting a purchased one – use this break to apply oxalic acid. Monitor the supers-off window before adding supers, treat if needed. Do not apply any treatment not labeled for use with supers on during the nectar flow.

Post-flow and midsummer (June through July). Remove and extract honey supers. This reopens the products that may not be used with supers on (amitraz, thymol, coumaphos, fluvalinate, Norroa); supers-on products (Formic Pro, HopGuard 3, oxalic acid products including VarroxSan, MBG2X5G, OrganiShield) could already have been used during the flow if counts required it. Monitor promptly after super removal. In very warm weather, chemical options are constrained: formic acid and thymol both approach their upper temperature limits; oxalic acid strips and HopGuard 3 (labeled to 100 degrees F) remain available. Check counts and treat if warranted, then follow up.

Late summer (August through September). This is the decisive monitoring point. Every colony should be washed. If counts are at or above 2 percent, treat immediately. The winter bee cohort is being reared; delay is not available. Choose a product whose label temperature range fits the current conditions –

formic acid becomes more practical as nights cool in September. Complete treatment and take a post-treatment count at the end of the treatment period.

Autumn (October through November). Verify efficacy with follow-up counts. Requeen any colony whose queen is failing. Consolidate stores and reduce entrances before the dearth. Address any collapsing colonies promptly – do not let them become mite bombs for neighbors.

Winter (December through January). If inspection confirms a genuinely broodless window, a single oxalic acid dribble or sublimation application is highly effective and removes the phoretic population at its most accessible. Broodlessness must be confirmed; in the warmer parts of the region, winter broodlessness may last only a few weeks or may not occur at all. Use oxalic acid extended-release strips if the colony cannot be confirmed broodless.

Throughout the year: keep written records of every count and every treatment. Record the product, the date, the pre-treatment count, and the post-treatment count. Without paired records, efficacy cannot be evaluated, resistance cannot be detected, and a pattern of escalating mite pressure across seasons cannot be seen.

12.15 Numbers to Know Cold

Figure	Value	Why It Is That Value
Alcohol wash sample size	~300 bees (half cup)	Enough for statistical resolution; practical in the field; can be converted to percentage directly
Infestation rate (spring build-up threshold)	1% (1 mite/100 bees), HBHC 9th ed.	A small spring mite population has months of brood rearing ahead in which to compound
Infestation rate (late summer threshold)	2% (HBHC 9th ed., peak and decline phases)	Winter bees are being reared; damage to this cohort cannot be corrected after the fact
Late summer treatment month range	August-September	Bees reared during this window become the overwintering cohort
Drone brood capped period	~14 days (capped ~day 10, emerges ~day 24 from oviposition)	About 2 days longer than worker brood's ~12-day capped period; allows more daughters to complete development and mate
Worker brood capped period	~12 days	Leaves only enough time for ~1 daughter to complete development in most cells
Mated daughters per foundress in worker brood (average)	~1.45	Tight developmental window; many daughters immature at emergence
Mating in sealed cells	Sibling mating, male mates with sisters only	No opportunity for outbreeding; male dies in cell; isolated from external gene pool
Brood break duration	About 3 weeks (up to 24 days with drone brood)	The last egg laid before the break must complete development and emerge

Figure	Value	Why It Is That Value
OA post-treatment count timing	A few days after a single dribble or vaporization	Enough time for dead mites to fall; before reinvasion distorts results
Strip treatment post-count timing	Promptly at strip removal, the end of the labeled period	Measures what the treatment achieved before reinvading mites can blur the result
Amitraz resistance mutation	Y215H in Octβ2R gene	Histidine substitution at position 215 alters octopamine receptor; amitraz fails to bind
Frequency of Y215H in 2026 Lamas et al. sample	100% of 39 mites screened	Up from ~66% in earlier surveys; all from amitraz-reliant operations
DWV-A prevalence (Lamas et al. 2026)	78% of pooled colony samples	Authors call mite-associated virus levels, especially ABPV, unusually high versus earlier national surveys
ABPV prevalence (Lamas et al. 2026)	72% of colony samples	Associated with winter collapse risk
DWV-B in symptomatic bees (Lamas et al. 2026)	100% of symptomatic bees	DWV-B now dominant strain
Formic acid temperature window	50-85 degrees F daytime highs (Formic Pro label)	Below 50: insufficient vapor; above 85: harmful to brood and queen
VarroxSan strip label duration	42-56 days	Spans a full brood cycle; allows contact with successive emerging mite cohorts
Tracheal mite susceptibility window	Mainly bees under ~4 days old	Spiracular sensilla not yet repelling mites; bees older than ~9 days are rarely newly infested
Natural mite drop rough indicator	No validated threshold; use for trends	Follow any noticeable drop with an alcohol wash; not a substitute for alcohol wash threshold

12.16 Common Misconceptions

Misconception: The late-summer count matters most simply because there are more mites in the colony at that time of year.

Correction: The count matters most because of which bees the mites are damaging. Bees reared from late August into October become winter bees – long-lived individuals whose physiology must sustain the cluster through winter. Mite feeding and virus transmission during their pupal development compromises them for life. A spring colony has months of turnover in which to replace damaged bees, but its mites also have months in which to multiply, which is why current HBHC guidance sets the spring action level even lower, at 1 percent. The late-summer level (2 percent) must be acted on at once because the cost of each mite is highest then and there is no later window in which to recover.

Misconception: A sugar roll gives the same result as an alcohol wash, and I can use it interchangeably.

Correction: Sugar rolls consistently underestimate infestation relative to alcohol washes, and the underestimation is worse in humid conditions because the sugar clumps rather than coating bees individually. Using a sugar roll for a management threshold decision in late summer – when the stakes are highest – risks concluding a colony is below threshold when it is actually above it. The alcohol wash is the reference method for a reason. Use the sugar roll when you need a non-lethal count and accept that it may undercount; do not use it as a substitute for a threshold decision.

Misconception: Once I've treated for Varroa, I'm done until next spring.

Correction: Treatment is not complete until it is verified. A post-treatment count is the only evidence that the treatment achieved its intended effect. Without it, the beekeeper does not know whether the product worked, whether resistance is present, whether application conditions were met, or whether reinvasion from a neighboring collapsing colony has undone the treatment. Given the documented level of amitraz resistance, a beekeeper who treats with Apivar and never counts mites afterward may be running an uncontrolled mite population while believing the colony is safe.

Misconception: *Varroa* kills bees by sucking their blood.

Correction: The older understanding – that mites fed on hemolymph – was revised by Ramsey and colleagues in 2019 using fluorescent biostains and electron microscopy. The primary feeding site on adult bees is the fat body, a tissue central to immunity, vitellogenin production, detoxification, and overwintering. (On pupae in the sealed cell, Han and colleagues showed in 2024 that the mites feed mainly on hemolymph; the fat-body correction applies to the adult stage.) This distinction matters because fat body damage explains effects that hemolymph loss poorly predicted: suppressed immune function, reduced vitellogenin, shortened lifespan, and poor winter survival. More importantly, the mite's greatest harm is not feeding at all – it is the viruses it injects during feeding.

Misconception: If I rotate treatments every year, I'm protected against resistance.

Correction: Rotation protects against resistance only if the products rotated use genuinely different modes of action. Rotating between two amitraz-based products accomplishes nothing, since both act on octopamine receptors and cross-resistance is complete. Rotating among oxalic acid, formic acid, and amitraz does represent three different mechanisms. The rotation must be designed around mode of action, not brand name or calendar year.

Misconception: Drone brood trapping is a safe, easy way to reduce mite populations without chemicals.

Correction: Drone brood trapping is only effective if the drone frame is removed and destroyed before emergence on a strict schedule. A drone frame that is not removed on time amplifies the mite population rather than reducing it, because all the mites that chose that frame to reproduce are now released simultaneously with the emerging drones. The technique requires consistent discipline and is most appropriate for small operations with careful record-keeping. It is a supplement to monitoring and treatment, not a replacement.

Misconception: Screened bottom boards control Varroa effectively.

Correction: Controlled trials find that screened bottom boards reduce phoretic mite load by modest amounts – typically less than 15 percent – because the mites that fall through the screen are a small fraction of the total population, most of which is in sealed brood. Screened bottoms are valuable for monitoring (natural drop can indicate trends), for ventilation, and as one component of an integrated approach, but they cannot replace chemical or biotechnical intervention.

Misconception: Mites that survive a treatment have developed resistance because they adapted to the chemical.

Correction: Resistance is selection, not adaptation. Mites do not change in response to exposure; they do not learn to avoid treated surfaces and pass that behavior to offspring. Resistance mutations are heritable genetic changes that were already present in some mites before any treatment was applied. When treatment kills susceptible mites and allows resistant ones to reproduce, the frequency of the resistance allele in the population increases over generations. The mites did not adapt; the population composition shifted through differential survival.

Misconception: *Acarapis woodi* can be identified by looking at bees on the combs during inspection.

Correction: Tracheal mites are internal and microscopic. A routine comb inspection cannot detect them. Even knowing that a colony has *Acarapis* mites on the exterior of bees – the non-pathogenic external species *A. externus* and *A. dorsalis* also occur – says nothing about tracheal mite status. Signs like K-wing and crawling bees are suggestive but not specific. Definitive diagnosis requires dissection of the prothoracic tracheae under a microscope.

Misconception: A collapsing colony is only a problem for the beekeeper who owns it.

Correction: A colony collapsing under mite pressure is a mite source for every colony within flight range. As the guard bee population fails and the colony becomes unable to defend itself, neighboring colonies rob its honey and brood, and those robbers carry phoretic mites home with them. A single mite-bomb collapse can reinfest a dozen treated colonies within weeks. Prompt action on any collapsing colony – treatment, combination with a healthy colony, or removal – is an obligation to neighboring beekeepers as well as an act of responsible stewardship.

Misconception: Powdered sugar dusting is a reliable mite control that avoids the risks of chemical treatments.

Correction: Powdered sugar dusting removes some phoretic mites immediately after application, but the effect is transient, it reaches no mites in sealed cells, and no published controlled trial has demonstrated population-level control. The mites in capped brood – which at any given time may represent the majority of the colony's mite population – are completely unaffected. Powdered sugar causes no harm and may be useful for purposes such as confirming that mites are present, but presenting it as a control to a new beekeeper is among the more consequential errors in popular beekeeping advice.

12.17 Self-Check Questions

- Explain why *Varroa destructor* and *Varroa jacobsoni* are now considered separate species, and describe one practical implication of the narrow genetic base of the population that infests *Apis mellifera*.
- A foundress mite enters a worker brood cell just before capping. Describe, in order, the events that occur inside that cell until the adult bee emerges. What is the sex of the first egg, and why?
- The fat body finding of Ramsey and colleagues (2019) replaced an older model of *Varroa* feeding. Explain what the mite actually feeds on and why this revision better explains the observed pathology of heavily infested colonies.
- You take an alcohol wash from a brood frame in the first week of September and count 8 mites in your sample of 300 bees. Calculate the infestation rate, state whether treatment is indicated, and explain the biological reasoning behind the threshold you are applying.
- A beekeeper argues that a low count in May means they do not need to monitor again until the following spring. Why is this reasoning incorrect, and what monitoring schedule would you recommend for a southeastern US operation?
- Distinguish the mechanism of formic acid from the mechanism of oxalic acid as *Varroa* treatments, and explain why the distinction matters for a beekeeper managing brood-right colonies.
- A beekeeper reports treating with amitraz strips six weeks ago but finds the mite count is still above 3 percent. List, in order of likelihood, the explanations you would systematically eliminate before concluding that resistance is present. What evidence would help you distinguish treatment failure from reinvasion?
- Explain what rotation of modes of action means, name the modes available to US beekeepers, and explain why rotating between two products of the same chemical class provides no protection against resistance.
- You find a dead colony in January. There is honey in the frames, but the cluster area is filled with bees with shortened abdomens, and you notice white deposits on the upper walls of brood cells near the cluster. What does this constellation of findings indicate, and what would you examine in the abandoned comb to confirm it?
- Explain why a colony that is being robbed out by neighbors after its population collapses is dangerous to those neighboring colonies even if the robbed colony's mite count was moderate rather than extreme.
- Why is drone brood trapping described as a discipline-dependent technique? What is the specific failure mode that turns a mite control measure into a mite amplifier?
- Describe *Acarapis woodi*: where it lives, how it enters a bee, why the bee's age determines susceptibility, and how a diagnosis is made. How does the principle illustrated by menthol treatment of tracheal mites apply to the use of formic acid and thymol for *Varroa*?

- A beekeeper in the coastal plain wants to time an oxalic acid dribble treatment for maximum efficacy. Describe the ideal colony condition for this treatment, explain why that condition is harder to achieve in the southeastern US than in northern regions, and identify two strategies for working around the constraint.

- The label for a thymol-based product specifies application only within a temperature window (roughly 60 to 105 degrees F for Apiguard; 64 to 95 degrees F for ApiLife Var). Explain the mechanism behind each end of this restriction, and describe the specific practical challenge this creates for beekeepers in the warmer portions of the southeastern US.

12.18 Self-Check Answers

- Anderson and Trueman's 2000 molecular analysis showed that mites reproducing successfully on *A. mellifera* are a distinct species from *V. jacobsoni*, the original *Apis cerana* parasite. Within *V. destructor*, only two haplotypes – Korean and Japanese/Thai – account for virtually all worldwide infestations of *A. mellifera*. The practical implication of this narrow base is that the mite behaves consistently worldwide: its reproductive biology, preferences, and resistance mutations are largely identical across all regions, so the global literature is directly applicable to any local situation. It also means that a resistance mutation arising anywhere is a signal with global relevance.

- The foundress mite enters the cell just before capping and conceals herself in the larval food. After capping, she and later her offspring feed on the developing pupa, mainly on its hemolymph, and she begins laying eggs. The first egg, laid about 60 to 70 hours after capping, is unfertilized and develops into a haploid male. Subsequent eggs, laid at approximately thirty-hour intervals, are fertilized and develop into females. The male matures first and mates with his sisters within the sealed cell. When the adult bee emerges, the foundress and her mature mated daughters leave with her, and the foundress can go on to invade further cells; the male and any immature daughters remain and die. The first egg is male because it is unfertilized – haploid development produces males in this arrhenotokous reproductive system.

- Ramsey and colleagues used fluorescent biostains and electron microscopy to show that mites on adult bees feed on fat body tissue, not in hemolymph-rich cuticle as previously believed. The fat body is the tissue responsible for immunity (producing antimicrobial peptides and supporting cellular immunity), for synthesizing vitellogenin (critical to both nurse physiology and winter bee longevity), and for detoxification. Hemolymph loss alone does not explain why mite-infested bees have suppressed immunity, reduced vitellogenin, and shortened lifespans – fat body damage does. The revision also explains why phoretic mite feeding on adult bees, once considered a minor effect of carrying the mite, is itself physiologically damaging.

- Eight mites in 300 bees is a rate of 2.67 percent, which is above the late-summer action threshold of 2 percent recommended in the Honey Bee Health Coalition's *Tools for Varroa Management*, 9th edition. Treatment is clearly indicated. The reasoning behind the threshold is that bees being reared in early September are the colony's overwintering cohort – the long-lived bees that must survive from autumn through the following spring. Mite feeding during their pupal development, which drains the hemolymph from which the fat body is built, combined with viral injection, compromises their immune function, longevity, and vitellogenin stores. Damage done in the pupal stage cannot be corrected after emergence. The threshold is low

because the cost of infestation at this time of year is much higher than at other times: a damaged winter bee cannot be replaced.

- A spring count is a starting point on a rising curve, not a prediction of future status. *Varroa* populations grow multiplicatively with each brood cycle: a colony starting at low infestation in May will typically reach damaging levels by late summer under unchecked reproduction, particularly in the southeastern US where the brood-rearing season is long, providing more mite generations per year than northern climates. A defensible monitoring schedule for a southeastern US operation is late winter or early spring (as brood rearing begins), mid-season (typically after the spring flow), and late summer (August at the latest) – with additional counts after any treatment to verify efficacy. The late-summer count is the most consequential and should never be skipped.

- Oxalic acid acts by contact on phoretic mites on adult bees and does not penetrate the wax cappings of sealed brood cells. Its efficacy in a brood-right colony is therefore limited to the fraction of the mite population that happens to be phoretic at the time of application – often a minority. Formic acid, by contrast, acts as a vapor that penetrates the cappings of sealed cells, reaching and killing mites in the reproductive phase. This makes formic acid the only widely available treatment that kills mites inside capped cells. Long-duration products (amitraz strips, extended-release oxalic acid) also work in brood-rearing colonies, but only by catching mites as they emerge over several weeks, not by reaching them in the cell. The practical consequence: in the southeastern US, where colonies are rarely broodless for extended periods, formic acid applied during the narrow temperature window in which it is both safe and effective can reach mites in capped cells as well as the phoretic fraction.

- In order of likelihood: first, confirm that a valid pre-treatment count was taken with correct methodology (if not, there is no baseline for comparison). Second, review application: was the dose correct for colony size? Were strips placed in the brood box rather than in a super? Were strips in place for the full label duration? Was the product properly stored and within its shelf life? Third, consider environmental conditions: amitraz efficacy is temperature-dependent and may be reduced in cool weather. Fourth, consider brood status at the time of treatment. Fifth, consider reinvasion: when exactly was the post-treatment count taken? A count taken promptly at the end of treatment reflects what the treatment did; a count taken weeks later after the colony has been exposed to robbing from neighbors may reflect mite immigration rather than treatment failure. Only after these are excluded does resistance become the leading explanation – and resistance should be confirmed by trying a product with a genuinely different mode of action and observing a better result.

- Rotation of modes of action means cycling among treatments that act on different molecular targets in the mite, so that resistance to one product does not confer resistance to another. The modes available to US beekeepers include: organic acid contact toxicity (oxalic acid), organic acid fumigant action penetrating cappings (formic acid), octopamine receptor agonism (amitraz), monoterpenoid vapor and contact (thymol), acetylcholinesterase inhibition (coumaphos), sodium-channel modulation (the pyrethroid tau-fluvalinate), hop beta acids (HopGuard 3), RNA interference (Norroa, active ingredient vadescana), and biotechnical methods such as brood interruption that require no chemical at all. Rotating between two products within the same class – two formulations of amitraz, or amitraz and a hypothetical second octopamine agonist – provides no protection because resistance to the shared molecular

target protects against both products simultaneously. Cross-resistance within a class is complete.

- The findings describe a colony that died with food in reserve but not enough live bees to form a viable winter cluster – the characteristic signature of *Varroa*-associated autumn collapse. Shortened abdomens and deformed wings indicate high deformed wing virus titers, which are almost always associated with heavy mite infestation and virus vectoring. The white deposits in the brood cells are guanine, the nitrogenous waste product of mite reproduction, and they persist long after the mites themselves are gone – which makes them especially useful diagnostic evidence in a dead colony. To confirm, examine the abandoned brood cells for mite fecal deposits, look for any remaining mites in cells or on the comb, and note the pattern of the dead cluster relative to the stores.

- A collapsing colony – one whose population has declined too far to defend its stores – is robbed out by neighboring colonies. Robbing bees enter the weakened hive, collect honey and may contact brood, and return home carrying phoretic mites that were living on the dying colony's bees. Those mites enter the robbing colony's brood nest, where they find cells to reproduce in, and the infestation grows accordingly. This mechanism, called mite bombing, can reinfest a carefully treated neighboring hive within weeks. The risk is not proportional to the collapsed colony's mite count alone – even a moderate mite load becomes concentrated exposure for the robbers if the robbed colony is large enough and the robbing event intense enough.

- Drone brood trapping works by concentrating *Varroa* reproduction in a compartment the beekeeper controls. Mites preferentially enter drone cells because the longer capped period allows more daughters to complete development. The failure mode occurs when the drone frame is not removed before the drones emerge. Drone brood has a capped period of approximately fourteen days; if the frame is not removed by around day thirteen of capping (roughly day twenty-three from oviposition), the mites that chose that frame for reproduction emerge with the drones and immediately reenter the brood nest fully mated and reproductively capable. A frame left too long does not just fail to trap mites – it amplifies the population by timing a synchronized reproductive cohort release, which is worse than not trapping at all.

- *Acarapis woodi* lives inside the prothoracic tracheae – the primary air tubes of the thorax – and enters through the first thoracic spiracle on the front of the thorax. Bees under about four days old are the most susceptible because the spiracular sensilla that deter mite entry are not yet fully developed; susceptibility falls sharply after that, and bees older than about nine days rarely acquire a new infestation. Diagnosis requires dissecting the prothoracic tracheae from an adult bee and examining them under a dissecting microscope: healthy tracheae are creamy white and translucent, while infested ones are cloudy or discolored with dark blotches, and the mites themselves are visible only under magnification. The principle illustrated by menthol treatment – a volatile treatment's efficacy depends on maintaining a therapeutic vapor concentration inside the hive, not just on the quantity applied – transfers directly to formic acid and thymol for *Varroa*. Temperature, ventilation, placement, and entrance configuration all affect the concentration achieved, which is why those parameters appear on the label as requirements rather than suggestions.

- The ideal condition for a dribble or sublimation application of oxalic acid is a colony with no sealed brood, so that all mites are phoretic on adult bees and accessible to the contact action of the acid. In northern climates, a reliable broodless window occurs each winter. In the

southeastern US, winters are short and warm spells can restart brood rearing in December or January; a colony may not achieve true broodlessness, or may do so only briefly. Two strategies for working around this: (1) confirm broodlessness by inspection before applying and apply only when the condition is met, which may mean waiting and monitoring; (2) use extended-release oxalic acid strips (VarroxSan, label duration 42 to 56 days), which maintain continuous contact with emerging mites across a full brood cycle and do not depend on broodlessness for efficacy.

- At the lower end of thymol's temperature range (roughly 60 to 64 degrees F, depending on the product), the compound sublimes and volatilizes so slowly that the concentration inside the hive remains below the therapeutic level – the treatment simply does not produce enough vapor to be effective. At the upper end (95 degrees F for ApiLife Var, 105 degrees F for Apiguard), thymol volatilizes rapidly and concentrations rise above what bees and developing brood can tolerate, causing brood removal, a temporary halt in queen laying, and potential queen loss. In the warmer parts of the southeastern US, summer temperatures regularly exceed 90 degrees F during the day, and the spring warming can arrive quickly. The effective treatment window – warm enough to generate therapeutic concentrations, cool enough not to harm brood and queens – is compressed into a few weeks in spring and a few weeks in autumn in the hottest parts of the region. Beekeepers at lower elevations in Gulf coastal and piedmont areas find thymol less useful as a summer treatment tool specifically because this window is so narrow.

12.19 Further Reading

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Honey Bee Health Coalition. Varroa Management Decision Tool. An interactive online companion to Tools for Varroa Management that suggests treatment options from the colony's season, mite level and whether honey supers are on; useful alongside the guide's monitoring methods.

Chapter 13. Small Hive Beetle, Wax Moth, Predators & Other Pests

Covers exam questions Q239-Q257.

13.1 Orientation

Most of the pests in this chapter did not evolve to destroy honey bee colonies. They evolved to exploit a resource: a warm, food-rich cavity that happens to be occupied by bees. What separates a pest that does modest, manageable damage from one that ends a colony is whether the colony's population can outcompete the intruder. That organizing idea – population as defense – runs through every topic here and is the premise the exam is built on. A candidate who understands it can reason through any scenario. One who has only memorized control methods is likely to fail the scenario questions.

The chapter covers three tiers of pest. The first tier consists of small hive beetle and wax moth, both of them true colony pests that kill or displace bees when they get the upper hand, both of them opportunists that a healthy colony can suppress. The second tier consists of vertebrate predators – bears, skunks, mice, and others – whose impact on colony health is direct but whose management is largely physical: fences, stand heights, entrance reducers. The third tier consists of insect pests and parasites: fire ants, yellowjackets, *Braula coeca*, velvet ants, and the zombie fly, each of which the examiner may probe for mechanism rather than just recognition. The chapter closes with *Tropilaelaps*, which is not yet present in North America but which represents the next plausible catastrophe in managed beekeeping.

The exam probes this domain at the level of mechanism, not prescription. Knowing that you should maintain strong colonies is not enough. You need to be able to explain what bees do to beetles, why a nuc cannot do it, why a shade-covered apiary on moist ground makes the problem worse, why slimed honey cannot be salvaged, and why wax moth damage in a living hive is a symptom rather than a cause. Every control recommendation in this chapter traces back to a biological principle. Find the principle and the recommendation becomes inevitable.

One theme deserves emphasis before you read further: the diagnosis question. When you find wax moth tunnels or a beetle infestation in an occupied hive, the correct first question is not "what do I apply?" but "what allowed this?" A colony that is populous, well-queened, and correctly sized for its comb will manage these pests on its own. A colony that is failing to do so has an underlying problem – queen failure, Varroa damage, disease, starvation, or a beekeeper who gave it more space than it could cover – and that problem will reassert itself even after you address the pest you can see. The habit of asking why separates a master beekeeper from one who merely maintains colonies.

13.2 Small Hive Beetle: A Subtropical Pest in a Temperate Hive

Aethina tumida is native to sub-Saharan Africa, where it co-evolved with *Apis mellifera scutellata* and with the entire community of African *Apis mellifera* subspecies. Those bees evolved alongside it. They chase beetles aggressively, trap them in propolis prisons, remove eggs and larvae before populations

build, and generally keep the beetle in a role analogous to wax moth in a healthy colony: a scavenger that exploits weakness without creating it. The beetle, correspondingly, evolved as a relatively minor hive pest in its native range.

The trouble began when *A. tumida* arrived in the Americas. The beetle was first collected in the United States in 1996, on the southeastern Atlantic coast, and identified in 1998; within a decade it had spread across the eastern half of the continent and into western states, eventually establishing on the West Coast and reaching parts of Canada. It has also established in Australia, where it has caused significant losses. The North American *Apis mellifera* subspecies – primarily European lineages selected over centuries for qualities that did not include intense beetle-harassing behavior – are ill-equipped by comparison. They confine beetles into crevices, they do some egg-chewing and larval eviction, but they cannot approach the efficiency of *A. scutellata*. That behavioral gap is why the beetle has become a serious pest here when it remained manageable in Africa.

The southeastern US is the beetle's most favorable territory on the continent. The warm, humid climate of the coastal plain, river swamps, and piedmont keeps soil temperatures high for most of the year, which allows multiple generations and near-continuous reproduction. More critically, the mild winters do not consistently kill pupae in the soil between seasons the way that sustained cold does in the upper Midwest or New England. In cooler climates, a hard freeze can interrupt the beetle cycle; in the southeastern lowlands, the beetle effectively never stops. This is not merely a detail about regional intensity; it shapes every management decision covered in this chapter.

13.3 The Life Cycle of *Aethina tumida*

Understanding the life cycle is prerequisite to understanding why control is difficult and which interventions actually work. The cycle has four stages, three of which occur inside or adjacent to the hive and one of which – the only one accessible to an out-of-hive treatment – occurs entirely in the soil.

Adult beetles in the hive. Adult beetles enter colonies through the main entrance or any crack wide enough to pass through. Inside, they are immediately recognized and harassed by the bees. In a strong colony this harassment is constant: guard bees chase beetles from frame to frame and crowd them into corners, propolis joints, and other crevices too narrow for the bees to follow them into. Once confined, a beetle may be held in place indefinitely. In a behavioral irony documented in the research literature, bees sometimes feed beetles by trophallaxis while keeping them imprisoned, apparently unable to refuse a soliciting insect at close range even when they recognize it as an intruder. Beetles in these "jails" may live for weeks. In weak colonies, where the guarding force is insufficient to maintain constant harassment, beetles move more freely, reach brood comb, and females oviposit without much interference.

Eggs and larvae. Females lay eggs in crevices and directly into brood comb cells containing eggs or young larvae. The eggs hatch in two to three days, which is fast enough that a weakening colony can fall behind the population math before the beekeeper's next inspection. Larvae are small, creamy white, and legless in early instars; they grow to about 10 millimeters at maturity. Their diet is catholic: pollen, honey, brood, and any organic debris in the hive are all consumed. Two aspects of larval behavior

deserve particular attention at the master level. First, the larvae defecate throughout the comb they are consuming, introducing *Kodamaea ohmeri* (a yeast), which ferments the honey and produces the characteristic frothy, foul-smelling, orange-tinged mass known as slime. A comb that has been slimed is unpalatable and unfit for any use. Second, larval populations grow quickly in warm conditions, and a colony that falls below the population threshold needed to control the adults quickly finds itself overwhelmed by larvae.

Soil pupation – the critical outside-the-hive stage. When larvae are ready to pupate, they leave the hive. They crawl down the front of the hive or exit through any available gap and burrow into the soil, typically within a few feet of the hive stand. They pupate at shallow depth – most within the top four inches (10 cm), occasionally down to about eight inches (20 cm) – and the duration of the pupal stage depends on temperature, with adults typically emerging after about three to four weeks and later in cool soil. This is the one life stage that occurs entirely outside the colony, which makes it the one stage vulnerable to a soil-applied insecticide. It also explains why an apiary can face sustained beetle pressure even when in-hive trap management has reduced the adult population inside the hives: the surrounding soil holds a developing cohort that the traps cannot touch. Newly emerged adults fly readily and can locate hive odors from considerable distances, so any colony in a beetle-pressure area is continuously subject to reinvasion.

Generations per season. Multiple generations can develop in a single season wherever temperatures allow soil pupation to proceed year-round. In the southeastern coastal plain and Gulf areas, the beetle effectively operates without a true seasonal break. This continuous reproduction is a large part of why the region requires a different level of management attention than areas that experience genuine winter interruption of the cycle.

13.4 Colony Strength: The Foundation of Beetle Management

The most important principle in small hive beetle management, and the one the exam tests most directly, is that a colony strong enough to patrol all of its comb is a colony that will manage beetles on its own. Every other tool – traps, drenches, sanitation, siting – supplements this principle. None of them replaces it.

The mechanism is direct. Bees suppress beetles by constant harassing behavior: chasing, biting, and confining individuals to crevices where they cannot reach brood comb or eggs. A colony at full summer strength covers its comb densely, and at that density no corner of the hive offers beetles a refuge they can exploit without being detected and harassed. When colony population drops below the threshold needed to cover the comb area in the box, beetles move freely, reach the brood nest, and female beetles begin ovipositing without interference. The transition from managed to overwhelmed can happen in as little as a week in warm weather if the population imbalance is large enough.

This mechanism has immediate practical consequences for hive management. Giving a colony more space than its population can cover is the single fastest way to enable a beetle infestation. The beekeeper who stacks two supers on a three-frame colony during a summer flow may return to find slimed comb in the empties. The correct practice is to add space incrementally as the colony fills what it

already occupies, and to remove it promptly when the flow ends. Never leave drawn comb in boxes the bees cannot patrol.

The vulnerability of small units deserves special attention because it shapes management of mating nuclei, splits, and swarm packages throughout the region. A nuc or split has few adult bees relative to its comb area by definition. It lacks the worker force of a full colony, and it typically lacks a laying queen for some period. During that time the population is declining from normal attrition while no new bees are being reared. A beetle population that a full colony would contain in a day can overwhelm a nuc within a week. Practical precautions follow directly from the mechanism: size the unit as tightly as possible, using follower boards to block off comb the bees cannot reach; reduce the entrance to a crack the bees can guard; install and maintain beetle traps; avoid large protein patties that attract beetles (use small pieces consumed within a day or two); place the nuc in a spot with morning sun rather than deep shade; and inspect on a tight schedule, since the gap between a nuc that is surviving and one that has been slimed out can be measured in days during peak beetle season. Any nuc that is visibly losing ground – population declining, brood area contracting, beetles moving freely in the box – should be combined with a stronger unit rather than watched to its end.

Apiary siting interacts with beetle pressure in a way that creates a genuine management trade-off. Heavily shaded sites on moist soil favor beetles because moist soil at moderate temperature is ideal for pupal development, and shade keeps soil temperatures from reaching the highs that would kill pupae or shorten their development period. On the other hand, full sun throughout the day in the southeastern summer creates heat stress for the colony and for the beekeeper. The practical resolution most experienced beekeepers in the region arrive at is morning sun on well-drained ground with afternoon shade from a tree line or structure that does not create a full canopy at ground level. Well-drained soil is the priority because it dries quickly after rain and is less favorable for pupation than persistently damp soil. Dense shade over wet ground is the worst combination and the one to avoid.

13.5 In-Hive Traps, Chemical Tools, and Soil Drenches

Physical traps inside the hive are a genuine tool, but they need to be understood as supplemental, not primary. The behavioral principle they all exploit is the beetle's compulsive tendency to seek refuge in narrow spaces when harassed by bees. This is the same instinct that drives beetles into propolis prisons – they will enter any crack or slot that is too narrow for a bee to follow. Traps exploit this by offering an attractive refuge that is lethal.

Oil tray traps. These are the most common in-hive trap design. They consist of a shallow tray filled with vegetable oil (or a mixture of oil and diatomaceous earth) that fits into or beneath the hive. Designs include the AJ's Beetle Eater, the Hood Trap, and various small tray designs that hang on frame top bars or sit in the screened bottom board. A beetle that enters the tray or slot and falls into the oil drowns. The traps require maintenance: oil evaporates in warm weather, and a trap that has run dry or is filled with debris and dead bees has no effect. Regular checking and refilling is part of using these devices correctly.

Corrugated cardboard traps with coumaphos. The miticide coumaphos (CheckMite+) is registered for use against small hive beetle in a specific configuration: impregnated strips cut to size and placed inside grooved or corrugated cardboard traps on the bottom board, where beetles shelter and make contact with the strip but bees cannot. This method provides an insecticidal supplement to physical trapping, but placement is critical – coumaphos in any location where bees contact it is a toxicant to the colony. Strips should never be placed on frames or in areas patrolled by bees. As with all coumaphos use, the concern about residue accumulation in wax is real, and this tool is typically reserved for high-pressure situations rather than routine prophylaxis.

Slotted in-hive traps. Several commercial designs present slotted openings that admit beetles but not bees. Beetles enter to escape harassment and drown in the oil below. These traps need to be charged correctly, checked regularly, and fitted properly for the hive dimensions where they are used.

Soil drenches. Because the soil-pupating larval and pupal stages are the only stages outside the colony, a labeled soil drench is among the few chemical controls that address the pest without treating inside the hive. GardStar 40% EC (permethrin, EPA Reg. No. 39039-8) is federally labeled as an aid in controlling small hive beetle around honey bee hives, applied as a soil drench (1 gallon per 16 square feet) to the soil immediately surrounding the hive stand. When hives are present, the label allows application only with a sprinkler can, never onto the colonies, and state rules may add limits. The application must follow label directions precisely: the right rate, the right timing, vegetation cleared so product reaches the soil surface, and careful placement so that runoff does not reach water. Soil drenches are most useful when beetle pressure is high enough to warrant chemical management, and they work best as one component of a program built on colony strength, sanitation, and trapping rather than the only tool employed. The label governs what is permissible; a beekeeper who uses any available insecticide on the theory that more is better is breaking the law and may damage the colony and contaminate hive products.

13.6 The Slime-Out: Recognition, Response, and Apiary Implications

A colony that has been overwhelmed by small hive beetle larvae produces a distinctive and unmistakable presentation: frames coated with a frothy, fermented material that smells strongly of rotting citrus or fermenting fruit, running between frames, orange or yellowish-brown in color, with beetle larvae visible throughout the comb. The honey is foamy and slimed. The bees, if any remain, are clustered in a corner or at the entrance and are visibly agitated. Often the colony has already absconded, leaving the slimed equipment behind. This is the slime-out, and there is no salvaging a colony in this condition.

The correct response begins with removing the hive from the apiary promptly. The odor of a slime-out is attractive to beetles from a considerable distance, and a slimed hive left in the yard will pull beetles away from your traps and into your other colonies. Do not leave it standing. If a recognizable cluster of bees and a living queen remain, you can shake them onto clean equipment and combine them with a stronger colony; whether this is worth the effort depends on how many bees are left and how strong your recipient colony is. In most severe slime-outs, there is no viable cluster to save.

The slimed comb must be destroyed. It is not suitable for feeding back to colonies, for melting into wax, or for any other reuse in a productive hive context. Feeding slimed material back introduces both the beetles whose larvae created it and the *Kodamaea ohmeri* yeast that fermented it. Scraping it into a bag and disposing of it away from the apiary is the correct treatment. Frames with limited damage – say, a corner of one frame where a larval cluster was caught early – can be cleaned and reused, but comb that has been heavily slimed should come off the frames entirely. The boxes, bottom board, and covers should be washed, scraped, and dried thoroughly, preferably in direct sunlight, before returning to service.

The critical last step, and the one that distinguishes a complete response from a tidy one, is inspection of the remaining colonies in the apiary. A colony that slimes out does not simply succumb to a random beetle invasion. It was overwhelmed because something else weakened it first – queen failure, mite damage and associated virus load, disease, starvation, or excessive space. That underlying problem is almost certainly present in the apiary and may be affecting other colonies. Find it. Look at your Varroa counts, assess your queens, check for disease signs, and think about whether any neighboring colonies have more space than they need. The slime-out is the end of one story but probably the middle of a larger one.

13.7 Protecting Comb During Storage

The moment drawn comb leaves bee protection, the population barrier to beetle and wax moth damage disappears. In the southeastern US this is not a theoretical vulnerability; supers removed from colonies in warm weather can be heavily damaged within 48 hours if they are not handled correctly. This urgency is one of the sharpest practical differences between beekeeping in this region and in climates where comb can be stacked in a barn for several weeks between extraction and storage without consequence.

Extract promptly. The most important practice is to extract within a day or two of removing supers from the colony. Wet supers after extraction should be returned to the bees within the same extraction session if possible, allowing them to clean out the residual honey and then come back under colony protection. If that is not practical, they need to go into a sealed environment or freezer.

Freezing. Freezing is the most reliable non-chemical treatment for both pests. Comb held at approximately 0 degrees F for 24 to 48 hours is killed at all life stages for both *Galleria mellonella* and *Aethina tumida*. Freezing does not harm the wax, does not leave residues, and is accessible to any beekeeper with a chest freezer. The important caveats are that comb must be sealed in plastic before freezing and allowed to return to room temperature inside the sealed bag (so that moisture condenses on the bag rather than in the cells when the cold comb meets warm air), that it must reach the target temperature throughout (not just at the surface), and that it must be stored pest-tight after removal from the freezer, because it will simply be reinfested if exposed. A common error is to freeze comb and then stack it in an outbuilding for the winter, which in this region means returning it to an environment where wax moth is active through most of the year, including warm spells in winter.

Light and airflow. Wax moth strongly avoids light and moving air. Comb stored in a space with regular airflow and light – for example, spaced stacks under a ventilated roof with open sides – sustains

significantly less damage than comb sealed in a dark building. This approach is more effective against wax moth than against beetle, since beetle larvae are less deterred by light. In the southeastern US, where wax moth remains active through most of the winter, this method requires consistent airflow and is not reliable on its own for supers stored over an extended period.

Bacillus thuringiensis subsp. aizawai (Certan). This biological preparation, registered for use against wax moth larvae, is applied to comb surfaces as a diluted spray. It does not affect the beetle but is an effective wax moth control and can be used on comb that will be returned to colonies. Follow label directions for application and storage.

What not to use. Paradichlorobenzene and naphthalene-based products (para-moth, moth crystals) leave residues in wax and honey and are not appropriate for comb that will be returned to food-producing colonies. The residues persist in wax over time, contaminate honey stored in treated comb, and cannot be removed by airing out in any reliable way. Although some label language distinguishes between uses, a master-level beekeeper should treat these chemicals as off-limits for any comb that will go back into a honey-producing hive. This is not merely a matter of label compliance; it is a product quality issue. The only safe storage methods for production comb are those that leave no chemical residue: freezing, light and airflow, and biological preparations like Certan.

The regional complication that the exam specifically tests is this: the mild winters of the southeastern coastal plain and piedmont do not interrupt wax moth development the way cold winters do farther north. A beekeeper accustomed to stacking empties in an unheated outbuilding and trusting winter temperatures to keep the moths suppressed will find that approach fails here. The moths do not die out, the damage continues, and spring brings comb that is destroyed rather than ready to use. Consistent practice – freeze before storing, keep stored in sealed or well-ventilated conditions, inspect before returning to colonies – is not optional in this region.

13.8 Sanitation in the Apiary and Honey House

Sanitation is unglamorous, but it is the practice that most reliably separates beekeepers who manage small hive beetle from those who are managed by it. The beetle and wax moth are both attracted to hive odors, to exposed wax and honey, and to dead equipment sitting unattended. Systematic removal of these attractants keeps pest pressure at manageable levels even when trapping and chemical management are imperfect.

In the apiary. Keep colonies populated correctly for their comb area. Reduce entrances on any colony that cannot cover its frames, and on all colonies during the late-summer and fall dearth, when robbing pressure and wasp pressure both peak. Service beetle traps on a regular schedule – an oil trap that has run dry or is choked with debris provides no protection. Remove burr comb, frame scrapings, and propolis from the apiary floor rather than leaving them at the hive stand, where they attract beetles and ants. Deal promptly with dead-outs: a dead colony sitting unattended with comb in it is a beetle nursery. Keep vegetation cleared from around hive stands, because dense grass holds moisture, provides cover for pupating larvae, and bridges between the ground and the entrance. Hive stands with legs in oil or grease cups prevent crawling insects from accessing the hive from below.

When a colony is lost to any cause, remove the equipment from the apiary the same day if possible. If it must remain, seal it tightly so beetles cannot enter, or freeze the drawn comb before stacking it for reuse. Never leave open dead-out equipment sitting in the apiary through beetle season.

In the honey house. Extract within a day or two of removing supers from colonies. Keep the extraction space as well-sealed against beetle entry as practical: door sweeps, window screens, and keeping doors closed during active processing are all meaningful. Cappings and wet comb are highly attractive to beetles and wax moth; process them or return them to the bees the same day rather than leaving them overnight. Return wet supers to colonies promptly after extraction, or freeze them, or seal them in plastic-wrapped stacks. Clean up honey spills and wax debris at the end of each processing session. A honey house that smells strongly of fresh honey and wax at the end of the day is one that will have beetle visitors by morning if the doors are not sealed.

13.9 Wax Moth Biology and the Comb It Prefers

Two species of wax moth are present in North American apiaries. The greater wax moth, *Galleria mellonella*, is the economically significant one. The lesser wax moth, *Achroia grisella*, is smaller, less destructive, and prefers dark used comb – worth knowing by name for the exam, but not a major management concern. The remainder of this section refers to *G. mellonella* unless otherwise noted.

The adult female *G. mellonella* is a dull gray-brown moth slightly smaller than a moth one might see around a porch light. She enters the hive at night to oviposit, avoiding the bee guard by moving quickly and at hours when bees are least active. In strong colonies she is almost always killed or expelled before she can lay. In weak colonies or during cool nights when guard activity is reduced, she reaches the brood area and deposits egg masses in cracks, between frames, and directly on comb.

Eggs hatch into larvae that immediately begin tunneling through the comb. The silk is the larvae' signature: as they feed and tunnel they spin continuous galleries of silk behind them, protecting themselves from bee attack. Bees cannot remove this silk without destroying the comb it is anchored to, so once a larval population is established in comb, the bees have lost that portion of the hive. The larvae feed on pollen, brood cocoon material, and pollen-contaminated wax. Old, dark brood comb is destroyed far faster than clean, new drawn comb because it is rich in pollen residue and protein from cocoon silk – the larvae can digest beeswax, but they need the protein in pollen and cocoon or pupal skins to develop well, and dark comb is protein-dense in a way that fresh white comb is not. This is a mechanistically important point: wax moth is not simply a wax eater. It is a protein scavenger that burrows through wax to reach its best food.

As larvae mature they begin searching for pupal sites. They chew characteristic excavations into the wooden parts of the hive – frame top bars, side bars, box walls, inner covers – to make shallow chambers in which they spin their cocoons. These boat-shaped depressions are diagnostic and memorable: they are smooth-sided, roughly the size of a thumbnail, and often found in clusters where multiple larvae pupated in the same area of woodenware. The cocoons themselves are papery, white, and difficult to remove without damage to the wood. The excavations persist in woodenware indefinitely even after the moths are long gone, and their presence tells you that wax moth found that

equipment at some point – though not necessarily that the colony currently in those boxes is weak. A single larvae that gained access through a crack in an otherwise strong colony can complete development and leave its excavation without the colony having failed.

13.10 Wax Moth as Diagnostic Tool, Not Primary Threat

The most important clinical fact about *Galleria mellonella* is that it cannot destroy a healthy, populated colony. This cannot be overstated, because the exam is built partly on the misconception that it can. A strong colony patrols its comb at sufficient density to find and evict wax moth eggs and young larvae before they establish. Wax moth is the cleanup crew of the bee world: when a colony dies from any cause, wax moth larvae move in within weeks and, in warm weather, consume the wax back to the bare wood in a matter of months. This is ecologically sensible – the larvae are breaking down organic material in an abandoned cavity – but it creates the misleading appearance that the moths killed the colony when in fact they arrived after the fact.

The clinical consequence is this: wax moth damage in an occupied hive is a symptom, not a cause. Finding silken galleries and frass in a living colony means the bee population has declined below the threshold needed to defend that comb. The moth exploited a vulnerability that already existed. The correct response is to find the underlying cause – assess the queen, run a Varroa count, look for disease signs, evaluate whether the colony has too much space – and address that, not merely to apply a wax moth treatment. Applying treatment without finding the cause is like treating fever with ice water: you may temporarily suppress the symptom while the disease progresses.

This diagnostic habit distinguishes competent beekeeping from symptom management. It applies equally to small hive beetle damage in a living colony. In both cases, the pest is telling you something about the colony's condition; your job is to read the message correctly.

13.11 Vertebrate Predators

13.11.1 Black Bears

Black bears (*Ursus americanus*) cause the most severe physical damage of any vertebrate predator on apiaries in the mountains and foothills of the southeastern interior. A bear raid is catastrophic in a way that most other pest damage is not: hives pushed over, boxes scattered, frames dragged into the vegetation, brood comb eaten, queens lost, and surviving colonies stressed and scattered. The bear's primary target is brood comb, which it eats for the larval protein; honey, if present, is consumed as well, but the mess of scattered wet equipment and destroyed brood comb is the characteristic aftermath.

The only reliable bear deterrent is a properly installed electric fence, and the most important management point is that it must be in place before the first raid. A bear that has successfully raided an apiary has learned that the site is a food source. It will return and persist through considerable deterrence, even through the discomfort of touching an electrified fence it has not been conditioned to respect. A bear that has never found food at your apiary location, by contrast, can usually be conditioned to avoid the site with a single contact with a well-grounded, adequately energized fence.

This behavioral asymmetry is why timing matters. Install the fence, energize it, and test it before bears are active in your area.

An effective electric fence for bear exclusion uses at least three strands, and preferably four to six, with the lowest wire no more than 8 inches above ground and the top wire about 36 to 42 inches, spaced no more than 8 to 12 inches apart (for example 4, 16, 26 and 36 inches, or 6, 16, 28 and 40 inches; Chapter 6), on well-grounded insulators with an energizer of adequate output for the wire run length and vegetation contact. Grounding matters most in dry weather, when soil resistance rises; extra ground rods improve reliability. Vegetation touching the wires bleeds off current and reduces effectiveness; clearing a strip beneath the fence line is not optional. Some beekeepers bait fence wires with aluminum foil strips smeared with peanut butter or honey to ensure the bear contacts the wire with its nose on the first encounter – the most sensitive and reliably aversive point of contact.

Bears are protected game animals. Shooting, trapping, and relocating them is governed by state wildlife law and is often restricted. In many jurisdictions, damage compensation programs require evidence of a functioning fence before damage occurred. Install the fence first and keep documentation of its installation.

13.11.2 Skunks

Striped skunks (*Mephitis mephitis*) are nocturnal and scratch at hive entrances at night, drawing out bees and eating them one by one. They do not typically destroy hive structure; the damage is the steady depletion of adult bees and the chronic agitation imposed on the colony. The bees come out to investigate the scratching, sting the skunk repeatedly, and are eaten. A colony that has been harassed for several consecutive nights loses workers and becomes persistently defensive during the day, stinging the beekeeper at routine inspections. Trampled or matted grass directly in front of the entrance, scratch marks on the hive front, and unusual daytime defensiveness together indicate skunk predation.

Skunks are low-slung animals and must expose their vulnerable underside to scratch at a hive entrance at ground level. Raising hive stands to 18 to 24 inches off the ground forces the animal to stand upright and stretch to reach the entrance, which it generally declines to do. Strips of carpet tacks or roofing nails placed face-up in front of the entrance also deter scratching. Cage traps can be used where legal and are often effective; check local regulations. Opossums (*Didelphis virginiana*) produce similar nocturnal scratching behavior and respond to the same controls.

13.11.3 Raccoons

Raccoons (*Procyon lotor*) can tip or disturb hives, particularly lighter nucleus colonies. They are less likely to fully disrupt a hive than a bear but can do enough damage to break propolis seals, expose comb, and stress the colony. Hive straps and adequate stand height reduce raccoon disturbance. Where raccoon pressure is persistent, a single electrified wire at about 8 inches above the hive stand platform deters most individuals.

13.11.4 Woodpeckers

Woodpeckers (primarily the downy and hairy woodpeckers, genus *Dryobates*, and the red-bellied woodpecker, *Melanerpes carolinus*) present a winter problem in areas where these birds are present.

During cold weather, a woodpecker may hear the sounds of a winter cluster moving inside a box and attempt to access the bees. They can create substantial holes in hive bodies in a short time. The simplest deterrent is wrapping the exterior of the hive body with hardware cloth – quarter-inch or smaller mesh – during the months when woodpeckers are most active. This does not interfere with hive ventilation and is easily removed in spring.

13.11.5 Mice

Mice enter hive boxes in fall when colonies contract onto their winter cluster and vacated portions of the box become available as nesting sites. The damage is to comb and to any wooden parts the mice gnaw. Mice also defecate extensively and can ruin frames that were otherwise in good condition. The prevention is simple and should be a standard fall practice: install a mouse guard – typically a metal strip with holes 3/8 inch in diameter – over the entrance when the colony's population begins to drop in autumn. The bees can pass through the holes freely; a mouse cannot. Remove the guard in spring when bee traffic resumes normal levels.

13.12 Insect Predators and Minor Pests

13.12.1 Imported Fire Ants

Imported fire ants (*Solenopsis invicta*) are a significant apiary pest throughout the coastal plain and Gulf coast region, and a genuine occupational hazard for the beekeeper. Their primary harm to colonies is overwhelming weak units: a nucleus colony or a newly hived swarm at or near a fire ant mound may be abandoned or destroyed as the ants rob brood and harass bees. A full, strong colony can usually defend itself against ant entry, but the same vulnerability that applies to beetles applies here – a colony that cannot cover its comb cannot defend its bottom board.

Fire ants also present direct danger to the beekeeper. Standing in an active mound while managing a hive is a risk that experienced beekeepers in the region have learned to screen for before setting down a hive body. Clearing vegetation around stands, moving hive locations away from known mound sites, and baiting mounds with a registered product applied at distance from the hives (so that hive products are not contaminated) are all practical steps. Hive stands with legs in oil or grease barriers prevent ants from climbing to the hive. Many beekeepers in the region use cinder block or pipe stands with each leg in a can of oil for this reason.

13.12.2 Yellowjackets and Hornets

Yellowjackets (*Vespula* spp. and related genera) and bald-faced hornets (*Dolichovespula maculata*) press on hive entrances in late summer and fall when their own colonies have reached peak population and natural food sources are declining. This peak in wasp pressure coincides with the regional dearth period, when honey bee colonies are already stressed, robbing pressure is high, and entrance reduction is already warranted. Managing for yellowjackets and managing for robbing are essentially the same practice: reduce entrances to a dimension the colony can guard, maintain colony populations, remove nearby wasp nests where this can be done safely, and use baited traps placed well away from the hives to draw wasps to a lethal destination rather than to the hive entrances.

The one response to avoid is applying insecticide at or near the hive entrance to kill wasps hovering there. This kills bees and contaminates the colony and any hive products. No pesticide application directly at an active hive entrance is appropriate.

Two exotic hornets are also of concern to beekeepers. The yellow-legged hornet (*Vespa velutina*), a honey bee predator, was first found in the United States near Savannah, Georgia in August 2023 and has since been found in South Carolina, first in the coastal Lowcountry and, by December 2025, as far inland as York County; it is under active eradication. Report suspected sightings (photo and location) to the state department of agriculture or Clemson DPI, and do not attempt nest removal yourself. The northern giant hornet (*Vespa mandarinia*) was declared eradicated from the United States in December 2024 after no confirmed detections since 2021.

13.12.3 *Braula coeca* (The Bee Louse)

Braula coeca is a wingless fly – not a mite – that lives as an ectoparasite on adult bees. The standard taxonomic distinction that the exam tests is the leg count: insects have six legs, arachnids have eight. *Braula* has six legs and is a fly (order Diptera), despite being called a "louse" in the older beekeeping literature and despite superficially resembling a mite at casual inspection. Adult *Braula* ride on adult bees – preferentially queens, which may carry several individuals – and steal food by intercepting it at the bee's mouthparts during trophallaxis. This is kleptoparasitism (food theft) rather than parasitism in the strict sense; *Braula* does not pierce the cuticle, does not feed on hemolymph, and causes little direct harm to the adult bee it rides.

The economically meaningful damage is done by the larvae. *Braula* eggs are laid beneath wax cappings on honey comb, and the larvae tunnel just beneath the capping surface, creating thin, winding channels visible as irregular marks on comb honey. This devalues comb honey sections but does not affect the honey itself. *Braula* was once widespread but has declined sharply in North America since the advent of synthetic miticides, because Varroa treatments applied to colonies also kill *Braula* adults. It is now uncommon, but beekeepers who encounter it – particularly comb honey producers who do not treat with synthetic miticides – should be able to identify it correctly.

13.12.4 *Apocephalus borealis* (The Zombie Fly)

The parasitic phorid fly *Apocephalus borealis* lays eggs in the abdomen of adult honey bees. The developing larvae cause behavioral changes in the host bee, including disorientation and abnormal nocturnal flight – the origin of the "zombie bee" name. The larvae eventually exit the bee through the neck region, killing the host. In honey bees this parasite has been documented mainly on the Pacific Coast, with scattered reports from other regions through citizen-science monitoring; for the exam, knowing the name and the basic biology (fly eggs in the abdomen, behavioral manipulation, mainly western range) is sufficient.

13.12.5 Velvet Ants

Velvet ants (*Dasymutilla* spp.) are actually solitary wasps – wingless females that closely resemble ants – found across the southeastern region. They turn up in sandy apiary sites, but they parasitize the nests of

ground-nesting bees and wasps and are not a documented pest of honey bee colonies. They are notable primarily for the intensity of their sting, a hazard to the beekeeper rather than the bees.

13.12.6 Robbing Bees

Robbing is not predation by another species but a colony-level stress worth covering in this chapter because its management overlaps with that of other pests. During the dearth, honey bees from other colonies attempt to steal honey from any available source, including neighboring hives. Robbing both stresses the target colony – which must divert workers to entrance defense – and can introduce disease if robbers come from infected colonies. Entrance reduction is the primary control. A strong colony can defend a reduced entrance; the same colony cannot defend a full-width opening against a determined robbing force. Identifying robbing in progress (orientation-lacking, frenzied bees at the entrance, fighting at the landing board, increased daytime defensiveness) and acting promptly to reduce the entrance prevents most serious robbing damage.

13.13 On the Horizon: *Tropilaelaps*

Two species of the genus *Tropilaelaps* are of concern to beekeepers: *T. clareae* and *T. mercedesae*, with the latter currently considered the greater threat to temperate-climate beekeeping. Both are brood parasites of *Apis mellifera* with a life cycle superficially similar to *Varroa destructor*'s – they reproduce in capped brood cells and damage developing bees – but with meaningful differences that make them both harder to detect and potentially faster-spreading under conditions favorable to continuous brood rearing.

T. mercedesae continues to expand its range westward. In 2025, a documented interception on an inbound cargo vessel carrying an *Apis dorsata* swarm marked the mite's proximity to North American arrival (reported in *Frontiers in Insect Science*, 2026). The mite is not established in the United States, and its interception is a biosecurity event rather than an outbreak, but the trajectory is clear.

For a master-level beekeeper, *Tropilaelaps* is worth understanding at the mechanistic level for two reasons. First, it is an obligate brood parasite and spends only a day or two on adult bees between brood cells – it needs brood cells for food and reproduction, unlike *Varroa*, which can sustain itself on adult bees for some time. Without brood it has traditionally been reported to survive only a few days (roughly 2-6 days on *A. mellifera*), although the vessel interception found live mites on a broodless *A. dorsata* swarm after at least 29 days, so a swarm or package can still carry viable mites over long distances. This means *Tropilaelaps* cannot spread by adult bee contact to the degree *Varroa* can, but it also means that the continuous brood-rearing conditions of the southeastern US – where colonies rarely go fully broodless even in winter – would provide exactly the conditions for rapid population growth if it arrived. A mite that requires brood will thrive where brood is continuous.

Second, and critically, the monitoring methods adapted from *Varroa* management are a poor screen for *Tropilaelaps*. Alcohol wash of adult bees detects *Varroa* because that mite spends significant time on adult bees between reproductive cycles. *Tropilaelaps* spends very little time on adults and therefore appears in low numbers on an alcohol wash even when infestations in brood are severe. Brood uncapping and bump-style examinations of uncapped brood are substantially more sensitive. Work

published in 2026 has confirmed this detection gap, which is operationally significant because the surveillance networks that monitor for exotic pests currently use methods calibrated for *Varroa*. Any beekeeper in a port-adjacent area or with colonies near apiaries importing package bees or queens should be aware that *Tropilaelaps* would be easy to miss with a standard mite wash.

Recognizing it on the comb is a matter of shape and gait. *Varroa* is broader than it is long - about 1.1 mm long by 1.6 mm wide - crab-shaped, reddish-brown and slow. *Tropilaelaps* is longer than it is wide - about 1 mm long by half that across - light reddish-brown, and runs quickly over the comb. Mites like that seen while uncapping brood, especially with an irregular brood pattern and some malformed wings, should be treated as a suspected *Tropilaelaps* find.

The response is a reporting response, not a treatment. Stop all movement of bees, brood, equipment and tools out of the apiary. Collect specimens into alcohol from the uncapped brood and photograph them. Record the hive and the location. Notify the state apiary inspector the same day; the inspector will involve the federal authorities and direct further sampling. Do not treat, move or destroy the colonies on your own initiative, since that can spread the mite or destroy the evidence an investigation needs. Early detection is the only realistic chance of eradication, and no product is registered against *Tropilaelaps* in the United States.

13.14 Numbers to Know Cold

Figure	Value	Why it is that value
SHB first detected in US	Collected 1996, identified 1998 (southeastern Atlantic coast)	Point of entry for a sub-Saharan pest reaching the southeastern US
Egg hatch time, *A. tumida*	2-3 days	Fast development drives rapid population buildup in warm conditions
Larval exit depth, SHB pupation	Mostly the top 4 inches (10 cm) of soil, occasionally to about 8 inches	Shallow enough to be reached by a labeled soil drench
Freeze temperature for comb sterilization	0 degrees F (about -18 degrees C)	Kills all life stages of SHB and wax moth; the standard treatment
Freeze duration for comb sterilization	24-48 hours	Time needed for the comb's interior to reach the target temperature throughout
Electric fence wire heights (bear)	At least three strands; four-strand example: about 4, 16, 26, 36 inches (or 6, 16, 28, 40)	Lowest wire within 8 inches of the ground and strands no more than 8-12 inches apart, so a bear cannot go under or between them
Entrance reduction for mice	3/8 inch diameter	Worker bees pass freely; mice cannot enter
Hive stand height to deter skunks	18-24 inches	Forces skunks to stand upright to reach the entrance; they typically decline

Figure	Value	Why it is that value
A. grisella vs. *G. mellonella*	Lesser vs. Greater	*G. mellonella* is the economically destructive species; *A. grisella* is less harmful
Braula coeca leg count	6	Insect (fly), not a mite (8 legs); diagnostic for distinguishing the two
Tropilaelaps adult survival without brood	About 2-6 days on *A. mellifera* (29+ days on a broodless *A. dorsata* swarm)	Obligate brood parasite with a short phoretic phase; does not persist on adult bees the way *Varroa* can
Wax moth larval food preference	Old dark brood comb	Larvae can digest wax but need protein (pollen, cocoon silk residue) to develop well; dark comb is protein-rich
Paradichlorobenzene appropriateness for production comb	Not acceptable	Leaves residues in wax and honey; cannot be adequately removed before return to colonies
Kodamaea ohmeri	Yeast introduced by SHB larvae	Ferments honey; produces slime characteristic of beetle-overwhelmed comb
Coumaphos strip trap placement	Where bees cannot contact	Coumaphos is toxic to bees; the trap design is specifically to exclude bee access

13.15 Common Misconceptions

Misconception: Beetle traps will save a weak colony if you put enough of them in. **Correction:** Traps reduce the number of adult beetles surviving inside the hive, but they cannot substitute for bee defense. A colony too small to patrol its comb has lost the behavioral mechanism that keeps larvae from reaching the brood. Traps kill some adults; the larvae that destroy the colony come from eggs already laid. Colony strength is the only foundational control.

Misconception: If I spray the slimed comb with a disinfectant and wash out the honey, I can salvage it and feed it back. **Correction:** Slimed honey is unfit for any reintroduction into a beekeeping operation. The yeast *Kodamaea ohmeri* persists in the material, and the odor of fermenting honey actively attracts more beetles. Feeding slimed material back introduces both the organisms and a powerful attractant. Destroy it and remove it from the apiary.

Misconception: Wax moth can destroy a healthy, strong colony if the infestation gets bad enough. **Correction:** A colony with adequate population to patrol its comb does not develop a significant wax moth infestation, because the bees find and remove eggs and early larvae before populations build. Wax moth is ecologically a secondary colonizer. Finding wax moth damage in a living hive means asking why the bee population dropped below the defensive threshold, not how to treat the moth.

Misconception: Paradichlorobenzene (para-moth) is an acceptable storage treatment for comb I plan to use next season. **Correction:** Para-moth leaves chemical residues in beeswax that persist even after the treated comb has aired out, and those residues contaminate honey stored in the comb once it is

returned to colonies. It is not an appropriate storage treatment for any comb that will be used in a food-producing hive. Freezing and biological preparations leave no residues.

Misconception: *Braula coeca* is a mite and should be counted alongside *Varroa* in a mite wash. **Correction:** *Braula coeca* is a wingless fly – an insect with six legs. It is taxonomically unrelated to *Varroa* (a true mite, an arachnid with eight legs) and operates through a different mechanism: riding on adult bees and stealing food at the mouthparts. The adult does not pierce the cuticle and causes little direct harm. The larvae damage comb honey by tunneling under cappings. It would appear in an alcohol wash, but it is counted separately because the biology, the harm, and the management are entirely different.

Misconception: A bear that has never raided my apiary is just as hard to deter as one that has. **Correction:** A bear that has successfully fed at an apiary has learned the location as a food resource and is far more persistent and deterrence-resistant than a naive animal. This is the behavioral reason that an electric fence must be in place before the first raid. A conditioned negative experience (nose contact with a charged fence) on a bear that has no food reinforcement at the site is typically sufficient to keep it away. The same fence on a bear that has already eaten brood comb there may only slow it down.

Misconception: Freezing comb kills American foulbrood spores, so I can safely give frozen frames from a dead-out to a healthy colony. **Correction:** Freezing kills all life stages of wax moth and small hive beetle in comb, but it has no effect on *Paenibacillus larvae* spores, which survive extremes of temperature and desiccation that would kill most living organisms. Equipment from an American foulbrood dead-out must be treated by the methods that actually destroy spores – burning (in most jurisdictions) or gamma irradiation – before reuse. Freezing is not a foulbrood sterilization method.

Misconception: Wax moth excavations (boat-shaped depressions) in woodenware mean the colony was weak when the damage occurred. **Correction:** A single larva that gained access through a crack – even in a strong colony – can complete development and chew an excavation into a frame top bar before being detected and expelled. The excavation tells you moths were present, not that the colony failed to defend itself adequately. A colony can be strong and still have scattered individual excavations in its woodenware from larvae that got through.

Misconception: Full sun throughout the day eliminates beetle pressure by killing pupae in the hot soil. **Correction:** Full sun does create soil temperatures that deter pupation in some cases, but the extreme summer heat in the southeastern region also stresses the colony and the beekeeper. The practical management goal is morning sun on well-drained soil, not full-day unrelenting sun. Well-drained soil – which dries quickly after rain – is more important than sun alone in reducing pupation success.

Misconception: The soil drench for small hive beetle can be any available insecticide applied generously around the hives. **Correction:** Only products specifically registered and labeled for this use can be applied to soil around beehives, and they must be applied per label. Using unregistered products is illegal, risks contaminating hive products through runoff or volatilization, and may harm the bees. Label compliance is not bureaucratic formality; it is the only assurance that the product is safe for the intended use in proximity to a food-producing operation.

Misconception: An alcohol wash for *Varroa* will also detect *Tropilaelaps* if it is present. **Correction:** *Tropilaelaps* spends very little time on adult bees; it requires brood cells for feeding and reproduction and spends only a day or two on adult bees between brood cells. An alcohol wash of adult bees misses most of a *Tropilaelaps* infestation. Brood uncapping and bump-style examination of fresh brood are substantially more sensitive detection methods. This is a practical biosecurity matter, not academic: the monitoring systems in place for exotic mites currently use adult-bee methods calibrated for *Varroa*.

13.16 Self-Check Questions

- A new beekeeper has set up four colonies on an overgrown, shaded creek bank. Beetle pressure has been severe all summer. List four specific site and management changes that would reduce pressure, and explain the mechanism behind each.
- Explain why *Kodamaea ohmeri* matters for management of a slime-out, beyond the immediate loss of the colony involved.
- A colony inspection reveals silk tunnels and frass in several frames of a living, queen-right colony with bees on six of ten frames. What is the correct diagnostic sequence before deciding on a management response?
- A beekeeper returns from vacation to find a nucleus colony completely slimed out. The adult beetle count on neighboring full colonies is high. Describe your step-by-step response that afternoon and during the following week.
- Distinguish the mechanism by which a soil drench controls small hive beetle from the mechanism by which an in-hive oil trap controls it.
- You are storing thirty supers of drawn comb through the winter in the southeastern coastal plain region. You have a chest freezer large enough for four supers at a time, a storage building with open sides, and access to Certan. Describe a realistic storage protocol.
- A bear has just raided an apiary for the first time, destroying two of six hives. What are the first three things you do, and why does the sequence matter?
- Explain the behavioral principle behind all in-hive beetle trap designs. Why does this same principle create a management challenge that traps alone cannot solve?
- What is the diagnostic significance of boat-shaped excavations in frame top bars, and what is the common misinterpretation you should avoid?
- *Braula coeca* is described in an old beekeeping text as a “mite” with “eight legs.” State the two specific errors in that description and the correct biological classification of *Braula*.
- Describe four specific precautions for managing a mating nucleus during peak small hive beetle season, explaining why each precaution addresses the nucleus’s specific vulnerability.
- Explain why a bear that has previously raided an apiary requires a different approach than one that has not, and what management step makes this distinction practically significant.

13.17 Self-Check Answers

1. Move the apiary to a site with morning sun and well-drained soil, because moist shaded soil maintains the temperature and moisture that allow pupae to develop successfully; removing shade and improving drainage raises soil conditions unfavorable for pupation. Clear the vegetation around hive stands to eliminate the cover that holds moisture and bridges the ground to the entrance. Reduce entrances to match the colony's guard capacity, since a colony defending a full-width entrance against foraging beetles must spread its guard force more thinly. Ensure all colonies are populated to cover their comb area, adding follower boards or combining weak colonies, because the fundamental defense is bee patrol density. Each of these addresses a specific pathway by which the beetle gains access or survives to return.

2. *Kodamaea ohmeri* is the yeast introduced by beetle larvae that ferments honey into the characteristic foul-smelling slime. Its significance extends beyond the immediate dead hive in two ways. First, the odor of fermenting, slimed honey is a powerful attractant to beetles at considerable distance, which is why slimed equipment left in the apiary draws additional beetles into neighboring colonies. Second, feeding slimed material to other colonies introduces both the yeast and viable beetle eggs or larvae that survived in the material. The correct management response is prompt removal of slimed equipment from the apiary and destruction of the comb rather than any attempt to salvage or recycle it.

3. The correct diagnostic sequence begins not with treating the moth but with assessing the colony's underlying condition. Count the frames covered by bees versus the frames available to the colony – if the bees are failing to cover existing comb, determine why. Assess the queen: is she present, laying in a solid pattern, and producing worker brood? Run a Varroa count using an alcohol wash or sugar roll, because Varroa-related virus damage is a leading cause of population decline that allows both wax moth and beetle to gain ground. Look for disease signs in the brood. Ask whether the colony has more space than it can reasonably cover. Only after this assessment can you determine whether reducing space, treating for Varroa, requeening, or combining are the appropriate responses. The wax moth is a consequence; find the cause.

4. That afternoon: remove the dead nuc from the apiary immediately, so the odor does not attract beetles to the neighboring colonies. Seal it in plastic bags or wrap it tightly before moving it if possible. Assess whether any bees or a queen remain; if fewer than one frame's worth of bees are present, the colony is not worth saving. Destroy slimed comb; scrape and clean the box in the sun. Inspect all remaining full colonies for beetle activity, bee-to-comb ratio, and any early signs of colony deterioration. Service all in-hive beetle traps. During the following week: consider a labeled soil drench where the nuc stood if beetle pressure was severe, run a Varroa count on the full colonies, and revisit the question of what weakened the nuc in the first place – a recent split that was undersized, a failed queen, or inadequate protection during the vulnerable early weeks.

5. A soil drench targets the pupal and wandering larval stage outside the hive, the one life stage that occurs entirely in the soil. It intercepts the population before beetles can emerge as adults and return to the colony. An in-hive oil trap targets adult beetles already inside the colony, exploiting their tendency to seek narrow refuges and drowning them in oil when they enter the trap. The two tools address different life stages and are complementary rather than redundant. The soil drench addresses the

external reservoir; the in-hive trap addresses the current adult population inside the box. Neither addresses the underlying issue of whether the colony has sufficient bees to defend its comb.

6. Freeze supers in batches of four, spending 48 hours per batch at 0 degrees F to ensure all life stages of both wax moth and small hive beetle are killed at the comb interior. After each batch is frozen, remove and allow to warm inside a sealed plastic bag to prevent condensation inside the cells. Stack warmed supers in the open-sided building on a pallet off the ground, with supers oriented so that light can enter between boxes where possible (wax moth avoids light). Apply Certan diluted per label to the comb surfaces of supers where wax moth pressure has historically been highest. Inspect the stored supers monthly and refreeze any showing fresh damage. Remove supers from storage in spring, inspect before returning to colonies, and freeze any that have been infested during storage.

7. First, make the site safe: stand in a clear path to leave the apiary quickly, because a raiding bear often circles back. Assess which colonies survived and move survivors to the center of the apiary or to an alternate location if the site is accessible. Second, erect a temporary electric fence or move equipment off-site within 24 to 48 hours. The sequence matters because a bear that has fed successfully will return the next night, and any delay in establishing a deterrent effectively provides another raid opportunity. The conditioned bear is far harder to deter than a naive one; every additional successful feeding visit makes eventual exclusion more difficult. Third, contact your state wildlife agency as required; many states require reporting of bear damage and have specific protocols for compensation claims.

8. All in-hive traps exploit the beetle's instinct to seek refuge in narrow spaces that bees cannot enter. Beetles under harassment move into the tightest available crack or slot. A trap positions a lethal chamber – oil or a chemical strip – at the entrance to an attractive narrow refuge, so the beetle's own escape response leads it to the trap. The management challenge this creates is that the same instinct also leads beetles into propolis joints, frame spacers, and crevices in the hive that are natural refuges – where they survive, are sometimes fed by trophallaxis, and wait for an opportunity to reach brood comb. Traps intercept a fraction of the beetles using this strategy. The only comprehensive suppression of this behavior requires a bee population dense enough to maintain constant harassment so that beetles never have a moment of undisturbed access to brood comb.

9. Boat-shaped excavations in woodenware are pupal chambers chewed by mature wax moth larvae prior to spinning cocoons. They are diagnostic evidence that wax moths were present in that equipment at some point. The common misinterpretation is that their presence indicates the colony using the equipment was weak or failing when the damage occurred. This is not necessarily true: a single larva that entered through a crack can complete development and leave its excavation even in a strong colony that has since evicted all the others. The excavation is a historical record, not a current status assessment. Evaluate the colony's present condition directly – bee-to-comb ratio, queen status, Varroa level – rather than concluding weakness from old woodenware damage.

10. The old text contains two errors. First, *Braula coeca* is not a mite – it is a fly, a member of the order Diptera. The correct classification is that *Braula* is an insect. Second, insects have six legs, not eight; eight legs is the count for arachnids (mites, spiders, scorpions). *Braula* has six legs. The wingless body

form and the parasitic lifestyle on bees led early observers to describe it as a mite, but the leg count alone is diagnostic and is the standard exam point for distinguishing the two.

11. (1) Fill the nuc box tightly with followers or use a smaller box so the bee population covers all the comb. Without coverage, beetles move freely to any unpatrolled frame. (2) Reduce the entrance to a crack of about one bee width, so the available workers can guard it. A full-width nuc entrance cannot be defended by a small force. (3) Install and service an oil trap, which supplements the bees' defense in the early weeks when population is lowest. (4) Use only small protein patties consumed within two days rather than large patties that sit and attract beetles. Residual patties provide a food source for beetles and larvae independent of the colony's condition. Any nuc that is visibly losing population should be combined rather than maintained.

12. A bear that has fed at an apiary has learned the location as a food source through positive reinforcement. Subsequent negative experiences – contact with an electric fence – must overcome an established food-reward memory, and bears are highly persistent when food rewards are involved. A naive bear that encounters a charged fence at a location where it has never found food has no competing motivation to persist through the deterrent experience. This distinction makes the timing of fence installation operationally significant: a fence installed before the first raid is almost always effective; a fence installed after one or more raids may reduce damage but often does not eliminate return visits from a bear that has established the site as known food. Install the fence before bears become active in your area.

13.18 Further Reading

- Neumann P, Elzen PJ. "The biology of the small hive beetle (*Aethina tumida*, Murray) (Coleoptera: Nitidulidae): Gaps in our knowledge of an invasive species." *Apidologie* 35:229-247 (2004). The foundational review; required reading for any serious treatment of this pest.

- Ellis JD, Delaplane KS. "Small hive beetle (*Aethina tumida*) oviposition behaviour in sealed brood cells with notes on the removal of the cell contents by European honey bees (*Apis mellifera*)." *Journal of Apicultural Research* 47(3):210-215 (2008). Documents beetles laying into sealed brood and the bees' removal response.

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- Morse RA, Flottum K (eds.). *Honey Bee Pests, Predators, and Diseases*, 3rd edition. A.I. Root Company, 1997. Comprehensive coverage of all pests addressed in this chapter; the primary reference for vertebrate predators.

- Graham JM (ed.). *The Hive and the Honey Bee*. Dadant and Sons, 2015 edition. Chapters on pests and predators provide context and regional management guidance.

- Delaplane KS. Honey Bees and Beekeeping: A Year in the Life of an Apiary, 3rd edition. Georgia Center for Continuing Education, University of Georgia. Includes southeastern-specific guidance on small hive beetle and wax moth management.
- University of Florida IFAS Extension. Small Hive Beetle publications by Jamie Ellis and colleagues. Freely available online; the most regularly updated practical guidance for management in the southeastern region.
- Honey Bee Health Coalition. *Best Management Practices for Hive Health*. Available at honeybeehealthcoalition.org. Addresses integrated pest management including minor pests and sanitation.
- Frontiers in Insect Science. "Interception of an *Apis dorsata* swarm with *Tropilaelaps mercedesae* and *Kuzinia morsei* mites on a cargo vessel inbound to the United States." 2026. The 2026 report documenting the interception event; current as of this edition.
- Cooperative Extension apiculture publications from Auburn University, Clemson University Cooperative Extension, University of Georgia College of Agricultural and Environmental Sciences, NC State Extension, and LSU AgCenter all maintain current regional pest management guidance that reflects local beetle pressure and legal product availability.

Chapter 14. Integrated Pest Management & Treatment Pharmacology

Covers exam questions Q258-Q274.

14.1 Orientation

Integrated pest management is a decision-making framework, not a product list and not a philosophy. It tells you when to act, how to choose among possible actions, and how to verify that the action worked. It does not tell you to avoid chemicals, and it does not tell you to use them. A beekeeper who treats every colony every spring without measuring first is not practicing IPM. A beekeeper who refuses all treatment on principle is not practicing IPM. Both have made the same structural error: they have removed the decision from the loop.

In beekeeping, where the organism of concern is *Varroa destructor*, IPM rests on four linked stages. First, monitoring – quantitative measurement of mite loads at defined points in the season. Second, action thresholds – predetermined population densities that trigger a response, derived from what mite populations will do to a colony if allowed to grow unchecked. Third, selection of the appropriate tactic for the conditions at hand, which may be cultural, mechanical, chemical, or genetic. Fourth, verification – a follow-up count that confirms the tactic worked. If any stage is absent, the system fails. Monitoring without a threshold is just counting. Treating without verifying is hoping. Verifying without recording is information that evaporates when the season turns.

The exam tests this framework in two ways. It tests conceptual understanding – can you explain what makes a threshold a threshold, and why late summer is the critical window for Varroa management? It tests applied judgment – given a mite count, a time of year, a product, and a label requirement, what do you do next and why? The pharmacology material is not separate from the IPM material. Knowing that formic acid penetrates cappings is pharmacology. Knowing why that property matters in a region where colonies are rarely broodless is IPM. Neither half makes full sense without the other.

The three ideas that organize this chapter are: measurement precedes and follows every intervention; the mode of action of a product determines its limitations and its role in rotation; and the label is federal law, not a suggestion. Everything else in the chapter is a refinement or an application of one of those three ideas.

14.2 The Threshold Concept: Economic Injury Level, Action Threshold, and Why They Differ

To understand Varroa thresholds, it helps to understand where the threshold concept came from. Agricultural IPM, formalized in the 1950s by Stern, Smith, van den Bosch, and Hagen, introduced two related but distinct ideas. The economic injury level is the pest density at which the cost of crop damage equals the cost of control. Treating at or above this density is cost-effective; treating below it spends more on control than the pest would have cost. The action threshold – sometimes called the economic threshold – is set below the injury level, at the density where an intervention must begin in order to

prevent the population from reaching the injury level by the time the intervention takes effect. The gap between them has to accommodate the time lag between starting treatment and achieving control.

In beekeeping, the economic calculus shifts. The “damage” is not a crop loss priced at a commodity rate; it is impaired winter survival, shortened worker lifespan, and virus amplification within the colony. These are harder to price than corn bushels. For this reason, practitioners often prefer the term “action threshold” alone, bypassing the economic framing and treating the threshold as a colony-health benchmark derived from research. The Honey Bee Health Coalition *Tools for Varroa Management* (9th edition, June 2026) is the current authoritative source for these numbers.

What makes thresholds seasonal is the biology of both the mite and the bee. In spring, when the colony is expanding brood and mite populations are low from winter attrition, the current HBHC action level is 1 mite per 100 adult bees on an alcohol wash. Acting at that level prevents the exponential buildup that would otherwise occur as every available cell becomes a reproduction site. At Peak Population and Population Decrease the action level is 2 percent, and in most regions that level covers the summer and the late-summer winter-bee window. HBHC keys its thresholds to colony phase rather than the calendar: 1 mite per 100 bees or more in the Dormant and Population Increase phases, and 2 per 100 or more at Peak Population and Population Decrease. The mechanism behind the late-summer level is different and more urgent. This is the time when the colony is producing its long-lived winter bees – the individuals that must survive from October until the first significant brood-rearing of the following spring, a span of five to six months. These bees are long-lived because of the physiology they develop as adults, chiefly large vitellogenin and fat-body reserves. Mite feeding and virus transmission during pupal development impair that physiology. A mite feeding inside the cell during that period does not merely extract hemolymph; it severs the fat-body reserves and inoculates the developing bee with deformed wing virus. A bee that emerges from a mite-infested cell in late summer is unlikely to build the full fat-body and vitellogenin reserves she was supposed to have, and many such bees die earlier than they should.

The time lag makes this window uniquely dangerous: a mite count taken in August reflects reproductive events that happened three to four weeks earlier. By the time the count crosses threshold, the bees being reared in the most critical cohort have already been exposed. Treating immediately still helps – it stops future damage and reduces virus load – but every week of delay costs bees that cannot be regenerated. Delaplane and Hood (1999) gave the southeastern field basis for a late-season (August) treatment threshold and showed that treatment timing matters; the winter-bee mechanism comes from work such as Amdam et al. (2004). Use current HBHC guidance for specific numbers.

The practical consequence for exam purposes: waiting to see deformed wings or a collapsing population is not conservative management. By the time those signs appear, the injury level has already been exceeded, and the bees that were supposed to carry the colony through winter were damaged months before the colony failed.

14.3 Monitoring: Converting a Guess into a Number

A visually healthy colony can carry a mite load that will kill it. Most of the mite population is sealed inside capped brood cells where it is invisible and reproducing. During brood rearing only about a sixth to a quarter of the mites ride on adult bees (Chapter 4); the rest are reproducing in cells, so a wash yielding 2 mites per 100 bees represents a total hive mite population roughly four to six times larger than the adult count alone suggests. The bees look normal because deformed wing virus's most visible manifestations – crumpled wings, stunted abdomens, neurological dysfunction – appear only when the viral titer exceeds a threshold specific to each individual bee, and the early stages of infestation produce subclinical damage that impairs bee longevity and learning without producing obvious deformity.

Three monitoring methods are established and accepted: the alcohol wash, the sugar roll, and the CO2-based detection roll. The alcohol wash is the most widely validated for absolute counts and is the method recommended by the HBHC. A half-cup measure of bees (approximately 300 adults) collected from a brood frame where the queen is absent, agitated in 70 percent isopropyl alcohol, and rinsed through a double-mesh container into a white tray, yields a reliable phoretic mite count. Divide the number of mites by the number of bees (counted or estimated at 300 per half cup) and multiply by 100 to get mites per 100 bees. The sticky board method counts mite fall over 24 to 72 hours and reflects total colony infestation more broadly, but its variability limits its utility for precise threshold decisions; it is more useful for trend monitoring between counts.

The examiner's specific interest in monitoring is the distinction between what a count tells you and what a visual inspection does not. A count gives you a number with a threshold to compare it against and a time series to track across the season. Looking at a colony tells you how it appears today. These are not substitutes.

14.4 Non-Chemical Tools: The First Tier

IPM's premise is that non-chemical tools carry as much of the load as possible, so that when a chemical treatment is necessary it faces a population not pre-adapted to resist it. In Varroa management, the non-chemical toolkit has four categories: genetic, cultural, biotechnical, and mechanical.

Genetic control means selecting stock with documented behavioral resistance traits – hygienic behavior, varroa-sensitive hygiene (VSH), or suppressed mite reproduction (SMR, the trait later shown to be largely an expression of VSH; Chapter 5) – and propagating from within-apiary survivors rather than replacing every loss with purchased commercial queens from genetically unscreened sources. No currently available bee stock is fully resistant in managed-apiary conditions, but resistant stock measurably slows mite population growth and reduces the frequency of chemical intervention required.

Cultural controls include apiary siting and density, which affect reinvasion. A mite-burdened colony that collapses and is robbed by neighbors exports its mite population to every colony within foraging range. Reducing drift between colonies through staggered hive placement and alternating entrance direction reduces the passive mite transfer that occurs when drifting foragers carry phoretic mites from colony to colony. Apiary density matters: beekeepers operating under the assumption that their well-managed

colonies are insulated from neighbors' mite problems are often wrong, particularly in areas with high beekeeper density.

Biotechnical controls include drone brood trapping and induced brood breaks. Because *Varroa destructor* reproduces preferentially in drone brood – invading drone cells roughly five to ten times more often than worker cells, largely because the pre-capping stage of drone brood is attractive for longer – introducing frames of drone foundation into colonies and removing and destroying the capped drone brood before emergence can remove a significant fraction of the reproductive mite population. This method is most effective when drone production is naturally high and when the beekeeper is willing to commit to regular removal on schedule; partial removal yields partial results. Induced brood breaks through controlled queen removal or caging halt brood-rearing and concentrate the mite population on adult bees, where it becomes accessible to contact treatments such as oxalic acid. A thorough brood break followed by an oxalic acid treatment is the most complete mite knockdown achievable without synthetic acaricides.

Mechanical controls – bottom-board oil traps, in-hive sticky traps, and screen bottom boards – are useful tools of modest efficacy when used alone and meaningful contributors when integrated with the rest of the program.

The limitation of non-chemical tools is clear: at typical managed-apiary mite loads, they are insufficient alone. Their value is in reducing the baseline infestation rate, extending the time between required chemical interventions, and reducing the selection pressure that any single chemical applies. A beekeeper relying entirely on non-chemical methods must monitor more rigorously, not less, because the margin for error is smaller.

14.5 Oxalic Acid: Contact Toxin and Its Defining Limitation

Oxalic acid kills *Varroa* on contact (and possibly by ingestion), but its exact mode of action is not known. At concentrations achievable with the dribble or vaporization application methods, the compound kills phoretic mites on adult bees with greater than 90 percent efficacy in broodless or nearly broodless colonies. That parenthetical is the critical constraint: oxalic acid in any form does not penetrate wax cappings. Mites inside sealed brood cells are completely sheltered from the compound, regardless of application method or dose.

Four oxalic acid products are registered by the US Environmental Protection Agency for use in honey bee colonies and listed in the HBHC 9th edition (2026): Api-Bioxal (the original registered product, as a dribble or vaporization formulation), Api-Bioxal RTU, EZ-OX, and VarroxSan. VarroxSan is the one extended-release product – glycerin-impregnated cellulose strips that remain in the hive over a period of 42 to 56 days; bees walking over the strips pick up oxalic acid and spread it through the colony by contact. This extended-release formulation directly addresses the capped-brood limitation: by keeping active compound present in the hive across a full brood cycle (worker brood is capped for approximately 12 days), mites are exposed as they emerge with each new cohort of bees. Manufacturer-reported field trials, including Washington State (2021) and Michigan State (2023), showed VarroxSan strips lowering

mite loads in fall and summer; independent peer-reviewed evaluations are still limited. The label permits use with honey supers on.

For single-application dribble or vapor treatments, timing to a broodless or nearly broodless period is decisive. In the southeastern US, this creates a challenge not faced in northern climates: colonies in the coastal plain and Gulf coastal areas may never reach a fully broodless state, even in December. A colony with as little as one frame of capped brood will harbor a mite population that escapes a single-application treatment entirely. This is the most common reason for a disappointing post-treatment count in the region.

Repeat vaporization regimens, applied on a schedule designed to catch successive cohorts of emerging mites, can address the capped-brood problem without extended-release strips, but require appropriate operator protection: oxalic acid vapor is a respiratory hazard, and the label specifies an appropriately rated respirator, not a dust mask. Working outdoors does not substitute for the specified PPE.

14.6 Formic Acid: The Fumigant That Crosses Cappings

Formic acid's defining advantage over oxalic acid is that its vapor penetrates the wax cappings of sealed brood cells, reaching mites during the reproductive phase inside the cell. This single property makes it uniquely valuable in colonies with brood present, and makes it particularly relevant in the southeastern US where broodless periods are short or absent.

Formic acid acts as a fumigant. Its vapor accumulates in the hive atmosphere and interferes with cellular respiration at concentrations that bees mostly tolerate. The mechanism in mites specifically involves acidification of cellular compartments and disruption of enzyme function, though the precise molecular target is not as well characterized as the target of amitraz. The practical point is that the vapor is effective against mites in sealed cells as well as mites on adult bees, which is why properly timed formic acid treatment can achieve significant knockdown even in colonies with substantial brood.

The dose-response relationship for formic acid is narrower than for most treatments in the beekeeper's toolkit. Too little vapor, and mite mortality is incomplete. Too much, or applied at too high a temperature, and the beekeeper risks brood mortality, queen loss, bee mortality, or absconding. Temperature drives the vaporization rate: the same application that achieves adequate vapor concentration at 70 degrees F may produce toxic concentrations at 90 degrees F. Label temperature ranges are not conservative suggestions. They define the window within which efficacy and safety can be simultaneously achieved. In practice, summer temperatures in the southeastern coastal plain frequently exceed the label maximum for FORMIC PRO (85 degrees F daytime highs; a slow-release formulation over 14 days that succeeded the faster-release, 7-day Mite Away Quick Strips), restricting useful application to spring and fall.

Queen loss to formic acid – noted especially with the older fast-release MAQS and still possible with FORMIC PRO – is a well-documented risk that experienced beekeepers manage by checking queens several weeks after treatment. Some operations temporarily remove their most valuable queens before formic acid treatment and reintroduce them after, accepting a shorter treatment window in exchange for queen insurance.

14.7 Amitraz and the Synthetic Acaricides

Amitraz, sold in the United States as Apivar and Amiflex, is a formamidine compound that acts as an agonist at octopamine receptors in the mite nervous system. Octopamine is the invertebrate analog of the vertebrate neurotransmitter norepinephrine; activating its receptors disrupts normal neurological signaling in arthropods. Vertebrates have no octopamine receptor, which is one reason amitraz has a wider mammalian safety margin than the organophosphate acaricides, but it is not harmless to mammals: it acts on vertebrate alpha-2 adrenergic receptors, among other targets, and dogs are markedly more sensitive than rats (oral LD50 about 100 versus 500-600 mg/kg); it is not recommended for horses, cats or small dogs (Merck Veterinary Manual). The key point for IPM and resistance management is that amitraz acts on a completely different molecular target than either the pyrethroids or the organophosphates.

Tau-fluvalinate (Apistan) is a pyrethroid: it interferes with voltage-gated sodium channels, causing prolonged nerve depolarization and paralysis. Coumaphos (CheckMite+) is an organophosphate: it inhibits acetylcholinesterase, preventing breakdown of the neurotransmitter acetylcholine and causing continuous stimulation. When choosing products for rotation, the relevant question is not simply whether the products are chemically different but whether they act on different molecular targets. Rotating between two pyrethroid products – such as fluvalinate and a different synthetic pyrethroid – is not genuine rotation. Any mite population with resistance to tau-fluvalinate through modification of the sodium channel target will tolerate the second pyrethroid for the same reason. Amitraz-to-oxalic acid-to-formic acid represents genuine rotation because each works through a distinct mechanism. Norroa (active ingredient vadescana, GreenLight Biosciences), a dsRNA product registered by EPA in September 2025, is a further rotation option, used only when honey supers are off.

Apivar is applied as plastic strips impregnated with amitraz, which act by contact over the 6-to-8-week (42-to-56-day) treatment period: bees brush against the strips and spread amitraz through the colony. Amiflex is a short-course in-hive formulation applied in two doses per brood box. Efficacy falls in cold weather, when the cluster contracts and bee movement over the strips slows, which reduces its effectiveness in late fall. Strips must be removed at the end of the labeled treatment period; leaving them in longer does not improve efficacy and extends residue exposure unnecessarily. Apivar cannot be used when honey supers are present, because the label requires super removal. (The parent compound breaks down quickly and is less persistent in wax than tau-fluvalinate or coumaphos, although some breakdown products remain.)

Coumaphos and tau-fluvalinate share the property of high lipophilicity to a degree that makes them practically problematic. Both compounds accumulate in wax and persist there for years; old dark comb carries substantially higher residue loads than new comb. This wax contamination is not merely a honey-quality issue: in laboratory bioassays on adult workers, the fungicide prochloraz increased the toxicity of coumaphos, probably by inhibiting the cytochrome P450 enzymes that bees use to detoxify both agrochemicals and acaricides (Johnson et al. 2013). Effects of coumaphos residues on queens and drones are documented separately. Neither compound is routinely recommended for Varroa management in current practice, though they appear throughout the older literature.

14.8 Resistance: The Y215H Mutation and What It Means for Practice

Chemical resistance in *Varroa* is not a theoretical risk. The 2024-25 colony loss season produced data that should reshape every beekeeper's practice. Lamas and colleagues (2026), screening a small, non-random sample of mites from collapsing, amitraz-dependent operations in that loss event, found the Y215H mutation in the Octβ2R octopamine receptor gene – the specific amino acid substitution that confers reduced sensitivity to amitraz – in all 39 mites screened across 18 colonies and five operations, compared with approximately 66 percent in an earlier regional survey. This suggests that amitraz may have been ineffective in those operations; it is not a national prevalence estimate, and the authors identify viruses as a likely end-stage cause of the collapses. The high frequency is consistent with the selection pressure from heavy amitraz use.

This mutation does not mean amitraz is useless in every colony everywhere. It means that the assumption that an amitraz treatment worked, absent a post-treatment count, is no longer tenable. A beekeeper who places Apivar strips and removes them 42 days later, without counting mites afterward, may be managing a colony with a population she believes is controlled but is not. The Lamas et al. sample suggests that this scenario occurred in the operations studied; it does not show how widespread it was.

The appropriate response to suspected resistance is specific: verify that the treatment was applied correctly and that the apparent failure is not a product-handling or timing error, then test a product with a different mode of action. If a second treatment – with oxalic acid, formic acid, or thymol – produces a substantial mite drop where amitraz did not, the inference of resistance is supported. The appropriate response is not to increase the amitraz dose. Overdosing is both unlawful and counterproductive: the margin between the dose that kills mites and the dose that kills queens and brood is narrow, and a dose exceeding the label rate adds residue to wax and honey without proportionally improving mite kill. More relevantly, it intensifies selection: the few mites with the greatest resistance survive and become the next generation's founders. Document unexpected treatment failures and report them to the state apiary inspector; building a regional picture of resistance prevalence is a collective good.

Thymol (Apiguard, ApiLifeVar) relies on vapor production from a natural monoterpene. Its mechanism in mites involves vapor-phase toxicity to the nervous system through effects that differ from amitraz, formic acid, and oxalic acid, though the precise receptor has not been definitively established. Thymol efficacy is strongly temperature-dependent: adequate volatilization requires daytime temperatures consistently above 60 degrees F, and the compound performs poorly in cool shoulder seasons. In the hot, humid interior of a southeastern hive in July, thymol may volatilize too quickly, causing brood loss; in a cool November apiary, it may produce too little vapor to be effective. The temperature window in which it performs reliably is narrower in the southeastern US than in temperate northern climates, and it is less useful there as a result.

14.9 Post-Treatment Verification: The Control That Catches Resistance

Post-treatment verification is not an optional best practice. It is the mechanism by which the IPM loop closes, and in the current resistance environment it is the only way to distinguish a colony that has been controlled from a colony that has not. The Honey Bee Health Coalition's 9th edition (June 2026) treats post-treatment verification as a required element of the program.

The post-treatment count is taken promptly at the end of the labeled treatment period, whatever the product, because a count taken then measures what the treatment achieved before reinvading mites can blur the result - the distinction on which treatment failure versus reinvasion turns. For a single oxalic acid dribble or vaporization, that means a few days after application; for strip products, including the extended-release oxalic acid strips and amitraz, it means at strip removal; for formic acid, at the end of the labeled treatment period.

A count that does not drop to the expected level after correct application is a signal. First, verify the application: was the dose right? Were the strips properly inserted and in contact with bees? Was the temperature within range? Was the treatment period completed? If the application was correct, the working hypothesis is resistance. Switch the mode of action and treat again. Record everything, including the pre-treatment count, the product, the dates, the post-treatment count, and the outcome.

14.10 Label Compliance and the Federal Pesticide Framework

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), codified at 7 U.S.C. Section 136 et seq., establishes the legal framework for pesticide use in the United States. Under FIFRA, using a pesticide in a manner inconsistent with its labeling is a violation of federal law. This applies to every element of the label, not only to dose and target organism.

The practical consequences for beekeeping are specific. First, applying an in-hive miticide at a dose above the label rate is unlawful, regardless of the beekeeper's intent or the failure mode suspected. Second, treating with supers present when the label requires super removal is unlawful. Third, applying a product outside its labeled temperature range is unlawful. Fourth, using the product for a pest or condition not specified on the label is unlawful. There is no "good faith" exemption; the violation is the use, not the intent.

These restrictions are substantive rather than bureaucratic. Dose limits define the boundary between mite efficacy and bee harm. Super restrictions define the conditions under which residues stay within tolerance. Temperature limits define when volatile products achieve efficacy without harming brood and queens. Each restriction is derived from the data that supported the registration and reflects an actual risk.

A feature of the label that surprises some beekeepers: the personal protective equipment (PPE) section is not a manufacturer's recommendation. It is part of the legally binding label. Applying formic acid without the face shield and chemical-resistant gloves specified on the label is use inconsistent with the labeling. The PPE requirements are also substantive: concentrated formic acid causes severe chemical burns to skin, eyes, and the respiratory tract. The requirement for an appropriately rated respirator

when vaporizing oxalic acid reflects genuine occupational health risk. Working outdoors is not a substitute for the specified equipment.

Labels change when registrations are amended. The label on the box from last year may differ from the current registered label. The practice of reading the current label before each treatment season is not excessive caution; it is label compliance.

14.11 Record Keeping: Three Distinct Functions

A treatment record is not a regulatory formality. It performs at least three distinct functions that are relevant to master-level practice.

The first function is resistance detection. A series of paired mite counts – pre-treatment and post-treatment, recorded by product and lot number across seasons – is the only practical way to detect emerging resistance before it causes catastrophic losses. If a product reliably drops mite loads by 90 percent in spring and summer and then fails to achieve 50 percent knockdown in the following autumn, that trend is visible only in the record. Without it, the beekeeper assumes the treatment worked and the loss, when it comes, is attributed to winter, to disease, or to bad luck.

The second function is regulatory and food safety compliance. Records demonstrate that the beekeeper used label-compliant products, applied them at label doses, respected pre-harvest intervals, and maintained the traceability chain that buyers and regulators increasingly require. Lot numbers matter here: if a product performs poorly or causes injury, the lot number allows correlation with other reports and with any product-specific quality issue.

The third function is operational troubleshooting. When a colony fails despite treatment, the record allows the beekeeper to distinguish treatment failure from wrong timing, from reinvasion from neighboring colonies, from an application error, from a concurrent pathogen problem unrelated to mites, or from a product issue. Without a record, the beekeeper is working from memory, and memory of a treatment applied six weeks ago in the midst of a busy season is unreliable. A written record converts an ambiguous loss into an analyzable data point.

The minimum useful record for each treatment includes: date of application, product name and lot number, dose and formulation, colony identifier, ambient temperature at time of application, mite count immediately before treatment, and mite count at the appropriate post-treatment interval.

14.12 Antibiotics and Veterinary Oversight

The regulatory change that brought honey bee antibiotics under veterinary oversight is part of the IPM story because it represents the same shift in paradigm that IPM itself demands: from calendar-based prophylactic treatment to diagnosis-driven intervention. As of January 1, 2017, antibiotics classified as medically important antimicrobials – oxytetracycline, tylosin, and lincomycin – require veterinary oversight for use in honey bees. A Veterinary Feed Directive (VFD) is required for medicated feed (oxytetracycline); the oral powder products (oxytetracycline in syrup, and tylosin and lincomycin dusted in powdered sugar) require a prescription, so most honey bee antibiotic use is by prescription. Over-the-counter purchase and routine prophylactic use are no longer lawful.

The practical consequence is that a beekeeper wishing to treat for American foulbrood or European foulbrood now needs an established veterinarian-client-patient relationship before the disease appears. A veterinarian who has never seen a bee hive will struggle to diagnose foulbrood on demand during a clinical visit; the practical path is to identify a veterinarian willing to work with apiaries in advance, establish the relationship, and arrange for laboratory confirmation of disease when it occurs rather than treating on suspicion alone.

The antibiotic caveat that applies to this pharmacology chapter as much as to the disease chapter: antibiotics suppress the vegetative stage of *Paenibacillus larvae* but do not destroy spores. A treated colony that appears to recover has had its symptoms suppressed, not the disease resolved. Spores persist in the comb, the equipment, and the colony's foraging range. This is the fundamental reason that burning remains the standard disposal method for AFB-affected equipment in most jurisdictions.

The veterinary oversight rule is an IPM-aligned policy precisely because it requires diagnosis before treatment. Prophylactic antibiotic use selects for resistance and adds unnecessary compounds to the honey and wax. Diagnosis-based treatment applies the compound when a confirmed pathogen is present, at a dose and duration calibrated to the diagnosis.

14.13 The Treatment-Free Position: Framework and Obligations

The treatment-free approach to Varroa management has a coherent theoretical basis and a poor practical record in managed apiaries. Understanding both is essential at master level, because the position comes up in club settings where an experienced beekeeper's ability to engage honestly with it matters.

The argument in favor runs as follows. Treating every colony prevents the natural selection of mite-resistant genotypes. Under low colony density with frequent swarming, populations of *Apis mellifera* have been documented maintaining themselves without treatment, as in the Arnot Forest research of Seeley and colleagues and in isolated island populations. Chemical residues accumulate in wax and impair colony health chronically, setting up a cycle in which chemical use becomes self-reinforcing. On this view, the correct long-term answer is to breed out the susceptibility, not to suppress its consequences with chemicals.

The argument against is equally coherent in the context of managed apiaries. In areas of high beekeeper density – the suburbs, the piedmont, the river valleys – colonies that collapse from mites are robbed. Robbing transfers mites from a dying colony to every colony within foraging range, externalizing the mite burden onto every neighboring beekeeper's operation regardless of their management choices. A beekeeper practicing treatment-free in isolation, with no neighboring colonies within several kilometers, is making a private decision. A beekeeper in a region with dozens of colonies per square kilometer is making a decision that directly affects their neighbors. The second beekeeper's untreated collapsing colonies are a mite and virus source for the entire local apiary community.

The second practical problem is that most beekeepers attempting the treatment-free approach in managed settings do not achieve the natural selection they intend, because they replace losses with purchased commercial queens from unrelated stock rather than propagating from survivors. Selection

requires that survivors reproduce and their offspring be tested in turn; replacing losses with commercial packages resets the genetic baseline to the commercial mean, undoing whatever selection the previous season's losses accomplished.

Responsible treatment-free practice, if it is to justify the shared risk imposed on neighboring beekeepers, requires: rigorous monitoring (the obligation to know whether your colonies are a mite source does not disappear because you have decided not to treat); willingness to identify and remove collapsing colonies before they are robbed, rather than allowing them to die in place; honest accounting of losses; actual propagation from genuine survivors; and transparency with neighboring beekeepers about the operation's approach and its mite levels. A treatment-free beekeeper who meets these conditions can be said to be practicing the position responsibly. One who does not monitor, loses colonies over winter without knowing whether they were robbed out in autumn, and replaces them with package bees in spring is practicing neither treatment-free management nor IPM; they are practicing inattention.

14.14 IPM Applied to Small Hive Beetle

The small hive beetle (*Aethina tumida*) is managed by applying the same four-component framework used for Varroa, with controls scaled to the beetle's ecology. Monitoring is the starting point: count beetles observed during routine inspection, note larvae in comb, and empty and read in-hive or bottom-board traps. The beetle's pressure on a colony is context-dependent; a strong colony of five or six frames of bees can police its own comb and limit the beetle's reproductive access, while the same beetle population in a two-frame nuc will destroy it in days. Colony strength is both a monitoring variable and a cultural control tool.

Cultural controls are the first line of management. Keep colonies populous and sized so that bees can patrol all available comb; if a colony is weak, reduce its box volume by inserting a follower board rather than leaving frames of unguarded empty comb available for beetle oviposition. Reduce entrances on weak colonies. Avoid leaving excess protein patties in the hive after feeding; beetle larvae feed readily on the same protein sources as bee larvae, and a neglected patty is a beetle nursery. Apiary siting matters: morning sun that dries the ground under hives reduces the soil moisture needed for pupal development, since beetle pupation occurs in the ground beneath the hive. Larvae need moist soil to pupate; dry, well-drained ground reduces emergence, whereas soil type itself has little effect. Wet ground in the river swamp environments of the southeastern coastal plain favors the beetle.

Mechanical controls include in-hive oil traps and bottom-board traps. These are maintained and refreshed regularly; a trap that has been in the hive since spring and is full of beeswax debris and dead bees is no longer trapping beetles. Checked and refreshed every two weeks, oil traps capture adults reliably and reduce the population available for reproduction.

Chemical control is limited in options and reserved for high-pressure situations. A labeled soil drench applied to the soil within a defined perimeter of the hive kills pupal-stage beetles in the ground, applied strictly per label. The only in-hive chemical option labeled for SHB is the coumaphos (CheckMite+) strip used under corrugated cardboard on the bottom board (Chapter 13); resistance and residue concerns

limit its use. A colony that is losing the battle – slimed combs, honey fermenting in cells, larvae visible throughout – should be combined with a stronger colony or removed entirely before it becomes a source of beetles for the rest of the apiary.

The organizing logic is the same as for Varroa: measurement first, cultural and mechanical tools carrying the primary load, chemical intervention reserved for situations where they are insufficient, results verified through continued monitoring.

14.15 Tropilaelaps: The Approaching Threat

Tropilaelaps mites do not yet constitute a domestic management problem in the United States, but they are close enough to the subject of Varroa management pharmacology that a master beekeeper should understand what they are and why they would be different to manage.

Tropilaelaps mercedesae is currently expanding its range westward in Asia. A 2026 report (Frontiers in Insect Science) documented interception of an *Apis dorsata* swarm carrying *T. mercedesae* on a cargo vessel inbound to the United States; the interception underscores that the pathway for introduction is not hypothetical. The mite's life history differs from *Varroa*'s in two ways that are relevant to monitoring and management. First, *Tropilaelaps* spends very little time on adult bees; it must return to brood to feed and reproduce and spends only a day or two on adult bees between brood cells. Second, its reproductive rate is faster than *Varroa*'s because it completes more generations per brood cycle. Where brood is continuous year-round – the exact condition in the southeastern coastal plain – *Tropilaelaps* populations can outpace *Varroa* population growth under equivalent conditions.

The monitoring challenge is a direct consequence of the mite's brief phoretic phase: alcohol wash methods calibrated to detect *Varroa*, which spends days on adult bees, will dramatically undercount *Tropilaelaps*. Work published in 2026 has raised specific concerns about the sensitivity of existing monitoring protocols for this organism. Detecting *Tropilaelaps* requires brood-focused methods – uncapping sealed brood and examining the contents, or modified bump/ether-roll techniques applied to brood comb. Beekeepers accustomed to a half-cup adult wash as a complete monitoring protocol would be poorly positioned to detect an early *Tropilaelaps* infestation.

No acaricides are currently registered in the United States for *Tropilaelaps*, and since the mite cannot survive long on adult bees, contact compounds designed to reach phoretic mites would have limited utility. This is worth noting as a conceptual point about IPM: control tools are matched to the organism's life history, not borrowed wholesale from the nearest analog.

14.16 Numbers to Know Cold

Figure	Value	Why it is that value
Spring action threshold	1% (mites per 100 bees), HBHC 9th ed.	Colony is building; early control prevents exponential mite growth during brood expansion
Late-summer action threshold	2%	Applies from Peak Population onward; winter bee cohort produced from late August into October; mite

Figure	Value	Why it is that value
		and virus damage during pupal development impairs winter-bee physiology; low threshold reflects how little margin exists
Time lag in mite counts	3-4 weeks	Counts reflect reproduction from 3-4 weeks prior; damage to currently-capped bees preceded the count
OA efficacy in broodless colonies	>90%	All phoretic mites exposed; no mites sheltered under cappings
Apivar strip treatment period	6-8 weeks	Bees spread amitraz by contact with the strips over this period; shorter periods miss mites emerging with late-cycle brood
MAQS treatment period (older product, replaced by FORMIC PRO; no longer listed by HBHC)	7 days	Fast-release formic acid; full dose delivered in one week; temperature limits apply throughout
FORMIC PRO treatment period	14 days	Slow-release; spreads dose over two weeks; lowers peak vapor concentration and queen loss risk
Post-treatment count (OA dribble/vapor)	A few days after application	Rapid action; mite mortality is nearly complete within days
Post-treatment count (OA strips)	At strip removal (end of the 42-56 day label period)	Measures the treatment before reinvasion blurs the result
Post-treatment count (formic acid)	At the end of the labeled treatment period	Measures the treatment before reinvasion blurs the result
Post-treatment count (amitraz strips)	At strip removal	A poor result then points to failure (application error or resistance), not reinvasion
Colony loss rate 2024-25	55.6%	Highest recorded in the annual US survey (2023-24: 55.1%); high Varroa and virus pressure is implicated
Colony loss rate 2025-26	39.9% (preliminary)	Improved but still roughly double the 15-20% beekeepers describe as acceptable
Y215H in screened mites (small sample)	100% of 39 mites from 18 colonies, 5 operations (2024-25)	~66% in an earlier regional survey; small non-random sample from collapsing, amitraz-dependent operations, not a national prevalence estimate
Drone brood preference factor	~5-10x worker rate	Pre-capping stage attractive for longer; drone cells capped ~2 days longer, so a foundress produces more viable daughters (~2 vs 1.3-1.5)
Acceptable annual loss (beekeeper-stated)	15-20%	Self-reported baseline from annual survey; 55%+ losses represent roughly 3x this benchmark
VFD/prescription requirement	Since January 1, 2017	Medically important antimicrobials (oxytetracycline, tylosin, lincomycin) require veterinary oversight (VFD

Figure	Value	Why it is that value
		for medicated feed, prescription for oral powders) in all food animal sectors including honey bees
OA products registered (US, 2026)	4: Api-Bioxal, Api-Bioxal RTU, EZ-OX, VarroxSan	VarroxSan registered December 2023 as the only extended-release OA product in the US
VarroxSan label period	42-56 days	Duration designed to span a full worker brood cycle (capped approximately 12 days) multiple times
HBHC Tools for Varroa Management	9th edition, June 2026 (cover date June 11; released June 22)	Current authoritative guidance; replaces 8th edition (August 2022)

14.17 Common Misconceptions

Misconception: IPM means organic – it's the approach where you don't use chemicals. **Correction:** IPM is a decision-making framework, not a philosophy about chemical use. It requires that decisions be based on measurement, that non-chemical tools be used where effective, and that chemical interventions be verified. A beekeeper who applies oxalic acid after a count exceeds threshold and follows up with a post-treatment count is practicing IPM. A beekeeper who refuses all chemicals without monitoring is not practicing IPM; they are practicing an untested belief.

Misconception: The action threshold is a universal number – if you're below it, you're fine. **Correction:** Thresholds are seasonal and regional. A 1 percent count during the spring Population Increase phase already calls for control under current HBHC guidance, because the mites have months of brood rearing ahead in which to multiply. A 2 percent count in late August, when the winter bee cohort is being produced, calls for immediate treatment. The threshold concept requires matching the number to the colony's phase and the season and understanding what the colony will do with that mite population over the next six to eight weeks.

Misconception: Once a colony looks healthy, the mite situation is under control. **Correction:** Colony appearance and mite load are decoupled through most of the buildup phase. The majority of mites at any moment are inside capped brood cells where they are invisible. By the time deformed wings and crawling bees appear, the mite population is near its seasonal peak and the winter bees have already been damaged during their development. Visual monitoring is not a substitute for a count.

Misconception: Oxalic acid vapor penetrates cappings, which is why it's effective in colonies with brood. **Correction:** Oxalic acid in any form does not penetrate cappings. The extended-release strips address the capped-brood problem differently – by remaining active across multiple brood cycles so that mites are exposed each time they emerge with a new bee cohort. Single-application OA treatments in colonies with substantial brood will show disappointing post-treatment counts for exactly this reason.

Misconception: Rotating between Apistan (tau-fluvalinate) and another pyrethroid is an appropriate resistance management rotation. **Correction:** Rotation for resistance management must change the mode of action – the specific molecular target in the mite. Both tau-fluvalinate and other pyrethroids act

on voltage-gated sodium channels. Any mite population resistant to one pyrethroid through sodium channel modification will tolerate the other pyrethroid for the same mechanistic reason. Genuine rotation moves between target sites: amitraz (octopamine receptors) to oxalic acid (contact) to formic acid (fumigant) to thymol (vapor toxicity), with Norroa (vadescana, a dsRNA product registered September 2025) as a further option when supers are off.

Misconception: If a treatment didn't work, increasing the dose next time will overcome the resistance. **Correction:** Increasing the dose above the label rate is a federal violation regardless of intent, and it is counterproductive against resistance. The margin between mite efficacy and queen and brood harm is narrow for most acaricides; overdosing kills queens and brood before it kills all the mites. Worse, the few mites that survive the overdose are the most resistant ones, which become the founders of the next generation. The correct response to suspected resistance is to switch the mode of action.

Misconception: The PPE requirements on the label are conservative suggestions that experienced beekeepers can waive. **Correction:** The PPE section is part of the legally binding label under FIFRA. Using the product without the specified equipment is use inconsistent with the labeling, which is a federal violation. The requirements are also substantive: formic acid causes severe chemical burns and respiratory injury; oxalic acid vapor is a respiratory hazard. Neither product becomes safer in the open air.

Misconception: A colony below threshold mid-season needs no further monitoring that year. **Correction:** A low mid-season count means no treatment is warranted at that time. It does not license abandoning the monitoring schedule. Mite populations grow exponentially through brood expansion; a colony at 1 percent in June can reach 4 percent or higher by late August depending on colony size, reinvasion pressure, and brood dynamics. The late-summer count – in late July to early August in most managed regions – is the most consequential of the season and cannot be skipped on the basis of a clean spring count.

Misconception: A beekeeper who doesn't treat can't be responsible for their neighbors' mite loads. **Correction:** When a mite-burdened colony collapses, it is robbed by every colony within foraging range. Robbing transfers phoretic mites to the robbers, who carry them home. In areas of high apiary density, an untreated failing colony is a mite export event that affects every neighboring beekeeper regardless of their management approach. The treatment decision in a dense beekeeping landscape has an externality that is not present in isolated, low-density apiaries.

Misconception: Sublethal effects of acaricides are only a concern at doses above the label rate. **Correction:** Effects on queen weight, acceptance, and survival, on drone sperm viability, and on worker learning and longevity have been documented at or near label-rate exposures, particularly in comb with accumulated residues. The interaction effects with agricultural fungicides appear at residue levels commonly found in pollen-rich environments, not only at elevated experimental doses. Queen producers using comb from treated colonies in cell builders and mating nuclei are exposed to these risks even when their own treatment practices are label-compliant.

Misconception: Beekeepers can use antibiotics at their discretion as long as supers aren't on the hive. **Correction:** Since January 2017, medically important antimicrobials including oxytetracycline, tylosin,

and lincomycin require veterinary oversight for use in any food animal sector, including honey bees. A Veterinary Feed Directive is required for medicated feed (oxytetracycline); a prescription is required for the oral powder products (syrup or powdered-sugar). The timing of super removal is a separate label issue and does not address the requirement for veterinary oversight.

Misconception: Formic acid is the ideal treatment for the southeastern US because it's always warm enough. **Correction:** The temperature constraint on formic acid runs in both directions. At high summer temperatures – the condition that prevails across much of the coastal plain from June through August – formic acid volatilizes faster than the label's target rate, producing concentrations that kill brood and queens. FORMIC PRO, like the older MAQS before it, specifies a maximum temperature (85 degrees F daytime highs), and that limit is frequently exceeded in summer across the region. Formic acid is most useful there in spring and fall, not in the peak mite-growth season when it might seem most needed.

14.18 Self-Check Questions

- Explain the difference between an economic injury level and an action threshold. Why does the distinction matter when making a treatment decision in late August?
- A beekeeper finds a 1.5 percent mite count on June 15 and interprets this as confirmation that the colony is in good shape for the rest of the season. Identify the error in reasoning and explain what should happen next.
- Describe the molecular target of amitraz and explain why alternating amitraz with tau-fluvalinate constitutes genuine rotation while alternating tau-fluvalinate with another pyrethroid does not.
- Why does oxalic acid's inability to penetrate cappings create a more serious limitation for beekeepers in the southeastern coastal plain than for beekeepers in northern climates?
- A beekeeper applies FORMIC PRO in mid-August when daytime temperatures are running at 92 to 95 degrees F. Identify both the legal problem and the biological risk.
- Describe the Y215H mutation, the receptor it affects, and the practical management implication for a beekeeper who uses amitraz as their primary Varroa treatment.
- Construct a minimal but sufficient treatment record for a single amitraz application. Explain the function of each field you include.
- Explain in plain language suitable for a new beekeeper why a colony can be heading toward collapse from Varroa without showing outward signs of disease.
- What is a Veterinary Feed Directive, when is one required for honey bee management, and what does it require the beekeeper to do that was not required before 2017?
- A beekeeper argues that their treatment-free philosophy means their colonies are contributing to natural selection for mite resistance in the local population. Under what conditions is that argument valid, and under what conditions does it fail?

- You apply an alcohol wash after removing your amitraz strips 21 days ago. The count is 3.5 mites per 100 bees, higher than the pre-treatment count. Walk through the steps you take to diagnose and respond to this result.

- Explain why drone brood trapping is a non-chemical control rather than merely a cultural practice, and describe the mechanism by which it reduces mite loads.

14.19 Self-Check Answers

- The economic injury level is the pest density at which the cost of damage equals the cost of control. The action threshold is set below it, at the density where intervention must begin in order to prevent the population from reaching the injury level by the time treatment takes effect. The gap between them must accommodate the time lag between starting treatment and achieving mite knockdown. In late August, this gap must be generous, because mite populations double quickly in colonies with substantial brood, and because the damage to developing winter bees occurs during pupation – weeks before the beekeeper can see it. A threshold set too close to the injury level in this window means winter bees are being damaged before treatment can stop it.

- The error is treating a single mid-season count as a season-ending verdict rather than one data point in a series. Mite populations grow exponentially through brood expansion, and a 1.5 percent count in June can reach 4 percent or more by late summer if the colony continues building brood and if reinvasion occurs from nearby collapsing colonies. Depending on the colony's phase, 1.5 percent may already exceed the action level (1 percent in Population Increase; 2 percent at Peak Population). The appropriate response to a June count below threshold is to record the result and schedule the next monitoring point, which should occur in late July or early August, when the critical window for winter-bee protection opens.

- Amitraz acts as an agonist at octopamine receptors, a target found in invertebrate nervous systems and absent in vertebrates; it disrupts neurological signaling in mites without the molecular machinery of sodium channel modification. Tau-fluvalinate acts on voltage-gated sodium channels, binding to the channel and holding it open, causing continuous nerve depolarization. Resistance to tau-fluvalinate typically arises through modifications to the sodium channel protein that reduce the binding affinity of the pyrethroid molecule. A mite resistant to tau-fluvalinate through that mechanism is not cross-resistant to amitraz because the two products act on entirely different proteins. A second pyrethroid would still bind – or fail to bind – to the same modified sodium channel, providing no rotation benefit.

- Oxalic acid's defining limitation is that it has no efficacy against mites inside capped cells. In northern climates, colonies routinely become fully or nearly broodless in December and January; a single OA application during this broodless period reaches the entire phoretic mite population, which is essentially the entire colony mite load. In the southeastern coastal plain, colonies may maintain some brood year-round, never presenting a truly broodless window. A single OA application in a colony with even one or two frames of capped brood will miss all the mites in those cells, leaving a reservoir from which the population rebuilds. Extended-release strips address this by providing continuous exposure across multiple brood cycles, but the limitation of the single-application method is structurally more severe in this region.

- The legal problem is that using a pesticide outside its labeled temperature range is a use inconsistent with the labeling under FIFRA, which is a federal violation. FORMIC PRO specifies a maximum of 85 degrees F daytime highs; 92-95 degrees F exceeds that range. The biological risk is that formic acid volatilizes at a rate proportional to temperature; at 92-95 degrees F, vapor concentrations inside the hive can exceed what bees tolerate, causing brood mortality, worker mortality, queen loss, or absconding. The damage to the queen is the most consequential, since a lost queen in August cannot be replaced in time to build the winter cluster population.

- Y215H is an amino acid substitution (histidine for tyrosine at position 215) in the Octβ2R protein, the octopamine receptor through which amitraz exerts its toxic effect on mites. Mites carrying this mutation have reduced sensitivity to amitraz at the target site, which means the same treatment dose produces less mite mortality than it would in a susceptible population. The Lamas et al. (2026) study found this mutation in all 39 mites screened, a small non-random sample from collapsing, amitraz-dependent operations in the 2024-25 high-loss event. The management implication is that an amitraz application in a colony where this mutation is present may produce substantially less than the expected mite knockdown. Post-treatment verification is therefore essential; a beekeeper who skips it may believe the colony is under control when it is not.

- A minimal sufficient treatment record includes: colony identifier (so results can be tracked to a specific hive); date strips placed and date strips removed; product name and lot number; ambient temperature on placement date and at intervals during the treatment period; mite count on the day before or day of placement; and mite count at the appropriate post-treatment interval (at strip removal for amitraz, the end of the labeled treatment period). The colony identifier allows longitudinal tracking. The lot number allows correlation of poor results with product-specific issues. Temperature documents whether the product was used within its effective range. The paired counts convert the treatment from an act of faith into a verifiable event and provide the data needed to detect declining efficacy over seasons.

- The short version, suitable for a new beekeeper: most mites are inside sealed cells where they are reproducing and invisible. The bees that hatch from those cells look normal to the eye but are internally compromised in ways that reduce their lifespan and suppress their immune function. The symptoms beekeepers recognize – deformed wings, crawling bees, a shrinking population – appear only when the infestation is severe and when virus loads, amplified by mite feeding, finally exceed each individual bee's tolerance threshold. By that point, the mite population is near its seasonal peak and, in late summer, the bees that were supposed to carry the colony through winter have already been damaged months earlier. A count transforms an invisible problem into a number before symptoms appear.

- A Veterinary Feed Directive is a written authorization from a licensed veterinarian to a client, specifying the use of a Veterinary Feed Directive drug in an animal feed formulation. Since January 1, 2017, antibiotics classified as medically important antimicrobials, including oxytetracycline, tylosin, and lincomycin, require a VFD for medicated feed (oxytetracycline) or a prescription for the oral powder (syrup or powdered-sugar) products when applied in honey bee colonies, the same requirement that applies in all food animal sectors. Before 2017, these products were available over the counter for routine, often prophylactic, beekeeper use. After 2017, the beekeeper must establish a veterinarian-client-patient relationship, obtain a diagnosis, and have a veterinarian authorize each use. Practically, this means the beekeeper

needs a working relationship with a veterinarian before the need arises, because emergency treatment under a new VFD requires the vet to have sufficient familiarity with the operation.

- The argument is valid when: the operation is isolated enough that collapsing colonies are not robbed before the beekeeper can remove them; the beekeeper monitors rigorously and removes collapsing colonies promptly; losses are honestly accounted; and replacements are propagated from documented survivors within the operation rather than from purchased commercial stock. Each of these conditions is required to achieve actual selection rather than mere attrition. The argument fails when: neighboring colonies are within robbing distance of any collapsing hive and the beekeeper allows the collapse to proceed; losses are replaced with commercial purchases rather than survivors' offspring; or the beekeeper does not monitor and cannot identify which colonies are becoming mite sources. In densely managed landscapes, even a beekeeper who meets all internal conditions can still impose mite and virus burden on neighbors, which is a community ethics problem that the individual argument does not resolve.

- First, rule out application error: were the strips fully inserted? Was the treatment period completed? Was temperature within the labeled range throughout? Second, calculate the expected efficacy: amitraz in a susceptible population should produce substantial mite knockdown; a count higher than pre-treatment is not a modest failure but a strong signal. Because the count was taken 21 days after removal, also consider reinvasion (robbing, drift) and brood-cycle rebound; a rise above the pre-treatment count still points to treatment failure, so confirm with a recount. Third, switch the mode of action immediately rather than repeating amitraz; treat with formic acid or oxalic acid (matching product to brood status and temperature). Fourth, recount at the appropriate post-treatment interval for the second product to confirm efficacy of the replacement. Fifth, document the entire sequence: product, dates, counts, temperatures, and outcome. Sixth, report the suspected resistance case to the state apiary inspector and consider submitting mite samples for genotyping if that service is available, because regional resistance data helps the broader community.

- Drone brood trapping is a biotechnical control that exploits the mite's reproductive preference for drone cells. *Varroa destructor* enters drone cells roughly five to ten times more often than worker cells, largely because the pre-capping stage is attractive for longer; drone cells are also capped for approximately two days longer, and the mite's reproductive success – the number of viable offspring she can produce per cycle – is higher in the extended reproductive period available in drone cells. By inserting drone foundation, allowing the queen to fill it, and removing the capped drone comb before adult drones emerge, the beekeeper destroys the mites that have entered those cells to reproduce. The mechanism is mechanical destruction of a mite population that has been attracted into an accessible substrate; it is not a chemical effect and leaves no residue, which is why it is categorized as a non-chemical tool even though it involves deliberate manipulation of the colony's reproduction.

14.20 Further Reading

Honey Bee Health Coalition. *Tools for Varroa Management: A Guide to Effective Varroa Sampling & Control*. 9th edition. Honey Bee Health Coalition (Keystone Policy Center), June 2026. The current authoritative guide for Varroa thresholds, product use, and monitoring protocols in the United States.

Delaplane KS and Hood WM. "Economic threshold for *Varroa jacobsoni* Oud. in the southeastern USA." *Apidologie* 30:383-395 (1999). The southeastern field basis for a late-season (August) treatment

threshold, showing that treatment timing matters. It does not address the winter-bee mechanism; use current HBHC guidance for the numbers.

Delaplane KS, van der Steen J, and Guzman-Novoa E. “Standard methods for estimating strength parameters of *Apis mellifera* colonies.” *Journal of Apicultural Research* 52:1-12 (2013). The reference for how to measure colony size in a standardized, comparable way; for mite sampling see Dietemann V et al. (2013), “Standard methods for varroa research,” *Journal of Apicultural Research* 52(1).

Lamas ZS, Rinkevich FD, Garavito A, et al. “Viruses and vectors tied to honey bee colony losses.” *PLOS Pathogens* 22(2): e1013939 (2026). The 2024-25 loss season analysis documenting 100 percent Y215H amitraz resistance mutation prevalence and the role of DWV and ABPV; essential reading for understanding why post-treatment verification has become mandatory.

Rosenkranz P, Aumeier P, and Ziegelmann B. “Biology and control of *Varroa destructor*.” *Journal of Invertebrate Pathology* 103:S96-S119 (2010). Comprehensive review of Varroa biology and management options; the mechanism sections underpin the pharmacology of this chapter.

Rademacher E and Harz M. “Oxalic acid for the control of varroasis in honey bee colonies – a review.” *Apidologie* 37:98-120 (2006). The primary review of oxalic acid’s mode of action and field efficacy; explains the capped-brood limitation in detail.

Johnson RM, Ellis MD, Mullin CA, and Frazier M. “Pesticides and honey bee toxicity – USA.” *Apidologie* 41:312-331 (2010). The reference for sublethal and synergistic toxicity of in-hive acaricides and agrochemicals; the coumaphos-fungicide interaction data are in Johnson RM, Dahlgren L, Siegfried BD, and Ellis MD. “Acaricide, fungicide and drug interactions in honey bees (*Apis mellifera*).” *PLoS ONE* 8:e54092 (2013).

Seeley TD. “Honey bees of the Arnot Forest: a population of feral colonies persisting with *Varroa destructor* in the northeastern United States.” *Apidologie* 38:19-29 (2007). The primary documentation of a surviving treatment-free population; read this before making claims about what natural selection can and cannot accomplish.

Stern VM, Smith RF, van den Bosch R, and Hagen KS. “The integrated control concept.” *Hilgardia* 29:81-101 (1959). The paper that established the economic injury level and action threshold framework; essential context for understanding where the concepts come from.

Vidal-Naquet N. *Honeybee Veterinary Medicine: Apis mellifera L.* 5m Publishing, 2015. The standard reference for veterinary aspects of bee health, including the pharmacology and the changed regulatory framework for antibiotics.

Graham JM (editor). *The Hive and the Honey Bee*. Dadant and Sons, 2015 edition. Chapter-level treatment of hive products, diseases, pests, and their management; the pharmacology and IPM chapters contain the integrated framework.

Delaplane KS. Honey Bees and Beekeeping: A Year in the Life of an Apiary, 3rd edition. Georgia Center for Continuing Education, University of Georgia. Practical seasonal calendar integrating monitoring,

threshold decisions, and treatment timing for the southeastern US; sold by the UGA Georgia Center (the free UGA Extension counterpart is Bulletin 1045).

University of Florida IFAS Honey Bee Research and Extension Laboratory. Small hive beetle management publications. Clemson Cooperative Extension and Auburn University Cooperative Extension publish complementary small hive beetle IPM guides for southeastern conditions.

Rinkevich FD. “Detection of amitraz resistance and reduced treatment efficacy in the *Varroa* mite, *Varroa destructor*, within commercial beekeeping operations.” *PLoS ONE* 15:e0227264 (2020). Bioassays showed amitraz resistance ranging from none to high among commercial operations, correlated with reduced Apivar efficacy; the paper predates identification of the Y215H marker.

Chapter 15. Pesticides & Environmental Hazards

Covers exam questions Q275-Q287.

15.1 Orientation

Pesticide exposure and environmental stress are subjects that experienced beekeepers often think they understand better than they do. A dead-bee pile at the entrance is dramatic, legible, and immediately linked in the beekeeper's mind to a spray event two fields over. But the dead-bee pile is only the most visible fraction of the pesticide problem, and focusing on it exclusively leads to missed diagnoses, failed communication with growers, and an incomplete picture of what is actually happening to colonies placed in agricultural landscapes. Master-level beekeeping requires an understanding of the full spectrum from acute kills through subtle sublethal effects, and a working knowledge of the tools – residue interpretation, label language, registration systems, and investigation procedures – that allow the beekeeper to move beyond suspicion into defensible analysis.

Three ideas organize everything else in this chapter. The first is that pesticide exposure is not a single event but a chronic, multi-route environmental condition: pollen carries residues home for weeks after an application, wax stores them for years, and guttation droplets serve up systemic compounds in concentrated form to thirsty foragers before most beekeepers are awake in the morning. The second is that lethality is not the right boundary for harm: a colony can be functionally damaged – navigational impairment, reproductive failure, immune suppression – with no dead bees to show for it, and these effects are harder to document precisely because they are real. The third is that the beekeeper's most effective tool is communication, not chemistry: advance notice from a cooperative grower is worth more than any hive treatment applied after the fact. Everything that follows is built on those three premises.

15.2 How Bees Encounter Pesticides: The Multiple Routes of Exposure

The earliest model of pesticide exposure imagined a spray drift landing on foragers at the flowers. That model led to a sensible but incomplete response: close the colonies during the application and let the material dissipate. The closure response fails because it addresses only one of at least six distinct routes by which pesticides reach bees.

Direct contact and drift are the most visible. A forager flying through a spray cloud or landing on a treated surface picks up material on her body; if the dose is high enough, she dies before returning. If she survives, she carries residues into the hive on the cuticle and in her crop, where nurse bees and house bees are then exposed during grooming and food exchange. Drift is not limited to obvious overspray: ultrafine droplets from ground rigs can carry hundreds of meters downwind, and aerial applications extend that radius further. Ultra-low-volume applications for mosquito control often produce droplets so fine that they remain airborne long enough to travel into apiary areas far from the target.

Foliage and flower surface residues persist after the spray has dried. A bee landing on treated foliage to collect water or resin picks up material through tarsal contact. A forager working flowers that were

treated before opening carries residues from the flower surface back to the hive in a mixture of nectar and pollen.

Contaminated nectar and pollen are the routes that make simple timing approaches insufficient. A contact insecticide applied in the evening when foragers are home may leave treated nectar and pollen in the flowers for foragers to collect the following morning. More critically, a systemic insecticide incorporated into the plant vascular system reaches nectar and pollen regardless of when the surface was treated. Once that pollen is packed into bee bread, nurse bees and brood are exposed continuously for weeks after a single application, long after any acute die-off would have been noticed and perhaps forgotten.

Guttation fluid is an underappreciated route. Plants release excess water from hydathodes at leaf margins, particularly in the early morning before evapotranspiration begins. This fluid can carry systemic compounds at concentrations far higher than the surrounding soil water, because the active ingredient is drawn up through the vascular system with the water flow. Bees actively collect guttation droplets as a water source, especially in the early morning when the drops are largest. Measured concentrations of neonicotinoids in guttation fluid from treated corn have been documented at levels acutely toxic to bees.

Seed-coating dust at planting deserves separate attention because it operates on a different schedule than a spray application. Seed treatments are applied to the outside of the seed before planting; when the seed is moved through pneumatic planting equipment, the coating is abraded and fine particles are expelled from the planter tubes as a dust cloud at ground level. Bees foraging near a planting operation in late spring, when dandelions and fruit trees are in bloom at the field margins, can be exposed to a pulse of highly concentrated dust containing the same neonicotinoids present at much lower concentrations in the later pollen and nectar. Some planting-time kills have been traced to this mechanism rather than to any direct spray.

Water contamination closes the list. Bees are opportunistic water collectors; they use puddles, drainage ditches, livestock troughs, and wet soil in preference to clean-running streams. A puddle at a field margin drains surface runoff that has carried pesticide residues across the treated area. A ditch receiving irrigation return flow from a treated field carries whatever the irrigation dissolved and moved. The beekeeper who places an apiary next to a reliable water source may be placing it next to a concentration point for whatever is running off the surrounding fields.

Taking all six routes together explains why closing the colony during an application is necessary but not sufficient as a protective measure. Residues that arrive as pollen and nectar after the beekeeper reopens the hive persist in the food stores and continue to expose the colony for weeks. The beekeeper's goal should not be to minimize the exposure event but to minimize total colony exposure across the season, which requires a different kind of conversation with the surrounding landscape.

15.3 The Toxicity Spectrum: From Acute Kills to Hidden Damage

Bee toxicologists use LD50 – the lethal dose for 50 percent of test bees – as the standard measure for comparing pesticide toxicity. The unit is micrograms of active ingredient per bee, and the test is

conducted by applying the compound to individual adult bees and measuring survival at 24 or 48 hours. The resulting number is the single most useful comparative anchor in the field, but it describes only acute mortality in healthy adult bees under laboratory conditions. That is a small corner of the full problem.

The EPA uses three categories of acute contact toxicity to honey bees:

- **Highly toxic**: LD50 below 2 micrograms per bee – most organophosphates and pyrethroids fall here.
- **Moderately toxic**: LD50 from 2 to 10.99 micrograms per bee.
- **Practically nontoxic**: LD50 of 11 micrograms per bee or more – herbicides and many fungicides land in this range for acute adult bee mortality.

Field-realistic exposure often differs substantially from the LD50 test. A forager collecting pollen from a treated plant does not receive the compound at a single dose; she accumulates residues across multiple foraging trips. Nurse bees receive the compound continuously through consumption of contaminated pollen over their entire brood-nursing period. Young adults consume bee bread as they develop their hypopharyngeal glands. The compound that was present at sub-lethal levels in any single food item may aggregate to a biologically meaningful total across the feeding period.

Acute effects are the deaths. Foragers die in the field and do not return; the hive entrance accumulates a pile of dead and dying adults; the colony loses its foraging force over a period of hours to days. The acute kill is visible, dramatic, and – critically – dateable. It can be matched against application records if those records are available.

Sublethal effects are the hidden problem. They occur at doses below the acute threshold and impair function rather than causing death. The best-documented sublethal effects include:

Navigation and homing impairment. Foragers exposed to sublethal doses of neonicotinoids or organophosphates show reduced ability to return to the hive. The colony loses foragers to disorientation in the field – they are not coming back, but they are not arriving at the entrance dead either. The result is forager loss with no dead-bee pile, which is exactly the symptom pattern that the beekeeper is most likely to attribute to something else.

Learning and memory impairment. Foraging efficiency depends on the bee's ability to learn the location, appearance, and odor of a rewarding flower, to remember that information through the return flight, and to communicate it in the dance. Compounds that impair associative learning reduce the colony's foraging efficiency per forager. The colony appears to be gathering less despite a field full of flowers. Under laboratory conditions, sublethal exposures to several neonicotinoids produce measurable deficits in learning assays; the magnitude of this effect under field conditions is harder to quantify but is documented.

Reduced immune competence. Sublethal pesticide exposure appears to reduce the expression of immune-related genes and to reduce bees' ability to mount a hemocytic response to pathogens. Colonies chronically exposed to field-realistic concentrations of fungicides show increased susceptibility

to *Nosema* and to viral infections. This is one pathway by which pesticide exposure and pathogen load interact rather than acting independently.

Queen reproductive failure. Several neonicotinoids produce measurable effects on queen reproductive output and egg viability at concentrations that do not prevent queens from appearing normal on inspection. Reduced egg-laying rate or increased egg failure produces spotty brood, which the beekeeper correctly diagnoses as a queen problem – but the queen problem has a pesticide upstream.

Drone sperm viability. Thiamethoxam and clothianidin have been associated with shorter drone lifespan and reduced sperm viability in caged-drone studies; total sperm numbers were not significantly reduced, and the field relevance is still uncertain. Drones that are structurally normal and fly to drone congregation areas may carry sperm with reduced viability, which could contribute to queen mating failure in subsequent generations.

The combination of impaired navigation, reduced foraging efficiency, reduced immune competence, and queen and drone reproductive effects means that chronic sublethal pesticide exposure can degrade colony performance substantially while producing no acute mortality event. The dead-bee pile is only part of the story. A beekeeper who dismisses pesticide as a possibility because no kill event was observed is using the wrong diagnostic criterion.

15.4 Insecticide Classes and Their Mechanisms of Action

15.4.1 Organophosphates and Carbamates

Organophosphates (OPs) and carbamates share a common mechanism: they inhibit acetylcholinesterase, the enzyme that breaks down the neurotransmitter acetylcholine at nerve synapses. When the enzyme is blocked, acetylcholine accumulates at the synapse and the nerve fires continuously. In insects, this produces a characteristic syndrome: tremors, paralysis, loss of coordination, and – at higher doses – death. In bees, the classic field presentation of acute OP or carbamate poisoning is a pile of dead and dying adults at the entrance with extended proboscises, visible leg tremors, and spinning, disoriented behavior in bees that are still alive. The tongue-out posture – the extended proboscis – is particularly characteristic and results from uncontrolled contraction of the proboscis muscles before death.

This presentation is suggestive but not pathognomonic. Chronic bee paralysis virus and certain bacterial infections of the hemolymph produce superficially similar adult mortality and behavioral abnormality. An acute organophosphate kill and a CBPV outbreak can look similar at the entrance; the distinction requires either laboratory confirmation of the pathogen or chemical analysis of the dead bees and environment.

Common organophosphates with bee-relevant exposure histories include malathion, used extensively in aerial and ground mosquito control programs across the southeastern US, and chlorpyrifos, used in agricultural settings, although its US food-crop uses have been sharply restricted and have changed repeatedly in recent years (check current registrations). Malathion is relatively fast-degrading, which means post-kill residue analysis requires rapid sample collection; delay of more than 48 hours can result

in samples that show no detectable residue even where the exposure clearly caused the observed mortality. Some OPs persist much longer, which cuts both ways: they continue to expose bees from treated surfaces for extended periods, but they are also more likely to be detectable in samples collected a week after the event.

Carbamates (for example carbaryl) are somewhat less commonly encountered in the southeastern agricultural landscape but operate identically at the synapse level. Carbaryl has historically been associated with kills when used as a dust on blooming crops.

15.4.2 Pyrethroids

Pyrethroids disrupt sodium channels in nerve cell membranes, holding them open and preventing normal nerve impulse termination. The acute bee toxicity of most pyrethroids places them in the highly toxic category (LD50 below 2 micrograms per bee). They are widely used in agriculture and around the home landscape, and their low mammalian toxicity relative to OPs has led to their displacement of OPs in many markets – a substitution that has not reduced bee risk.

One pyrethroid, tau-fluvalinate, is registered for in-hive use as the active ingredient in Apistan strips, and is the only pyrethroid with that registration. This is not because tau-fluvalinate is uniquely safe for bees but because the strip formulation limits exposure and because honey bees appear to tolerate it better than most other species of bee, likely due to differences in metabolic detoxification rather than receptor binding. The fact that a pyrethroid product is registered for in-hive use does not mean pyrethroids as a class are safe for bees; the class is broadly highly toxic.

Permethrin is commonly used around hive stands to control small hive beetle larvae and pupae in the soil and ant trails, applied to the soil rather than to the hive itself. The distinction matters for label compliance: applying a product not registered for apiary use to the hive itself is a federal FIFRA violation.

Evening and night applications greatly reduce bee contact with pyrethroid applications to foliage and crops because foragers are in the hive. Most pyrethroids degrade significantly in sunlight over a period of hours to a day or two, so a night application to a field that is not in bloom poses substantially less risk than a daytime application to a blooming crop, and the timing window matters.

15.4.3 Neonicotinoids: The Systemic Problem

Neonicotinoids are nicotinic acetylcholine receptor (nAChR) agonists. They bind to the same receptor that acetylcholine binds to in insect nervous tissue, but rather than triggering a response and then being cleared, they produce persistent receptor activation. The receptor keeps firing. The selectivity of neonicotinoids for insects over vertebrates derives from differences in the nAChR composition between the two groups: the vertebrate receptor binds neonicotinoids poorly, while the insect receptor binds them with high affinity. Honey bees are highly sensitive to some neonicotinoids (imidacloprid, clothianidin, thiamethoxam, dinotefuran) and far less sensitive to others (acetamiprid, thiacloprid). The difference lies mainly in how quickly the bee's cytochrome P450 enzymes (CYP9Q) metabolize each compound, not in receptor binding.

The defining characteristic of this class is **systemic activity**: the active ingredient is taken up by the plant's vascular system and distributed into all plant tissues, including roots, stems, leaves, pollen, and

nectar. A seed coated with imidacloprid grows into a plant that expresses the compound in its pollen and nectar at concentrations that, while lower than the seed treatment itself, are available to every bee that visits the flower. A soil drench treatment produces the same result via root uptake. This systemic mechanism changes the exposure equation fundamentally: you cannot eliminate bee exposure by timing the application away from foraging hours, because the compound is not on the plant's surface but inside the plant tissues the bee consumes.

The major neonicotinoids in use – imidacloprid, clothianidin, thiamethoxam, and acetamiprid – share this systemic mechanism but differ in acute bee toxicity and environmental persistence. Clothianidin and thiamethoxam are particularly persistent in soil; detected concentrations in soils of previously treated fields persist for multiple growing seasons, and uptake by wildflowers and weeds growing in or near treated fields has been documented. A beekeeper whose colonies are foraging apparent wildflowers at field margins may be providing access to residues from treatments applied one or more seasons earlier.

Seed treatments add a planting-time dust hazard distinct from plant tissue residues. When coated corn or soybean seeds move through modern high-speed pneumatic planters, the talc or polymer coating is abraded and fine particles become airborne at concentrations capable of producing acute kills in bees foraging near the planting operation. The European Food Safety Authority and several regulatory agencies have identified this route as responsible for documented kills, and modified planter deflectors and alternative lubricants have been developed to reduce dust generation – but these mitigations are not universally adopted.

In the United States, neonicotinoids remain registered for a range of agricultural and ornamental uses. The EPA's registration review process has examined the evidence base for pollinator effects and has resulted in some label changes, additional pollinator protection language, and restrictions on certain uses (for example, applications to blooming crops while bees are present), but the class remains widely available. The regulatory picture differs substantially in other jurisdictions; the European Union has imposed outdoor use bans on clothianidin, imidacloprid, and thiamethoxam since 2018. Master-level candidates should understand the distinction between what the evidence shows and what the current regulatory posture is, because they will encounter both in the field.

15.4.4 Fungicides: The Synergistic Problem

Fungicides present a different kind of risk than insecticides. Their direct, standalone toxicity to bees is generally low – most fall in the practically nontoxic range on the EPA LD50 scale. A beekeeper who looks at the label, sees no insecticide, and concludes that the fungicide tank mix is not a bee concern is making an error that the exam will probe.

The problem is synergy. Bees detoxify many compounds through a family of metabolic enzymes called cytochrome P450 monooxygenases. These enzymes are responsible for breaking down a range of foreign molecules, including some insecticides. Many fungicides inhibit one or more P450 enzymes. When a bee has consumed fungicides that suppress her detox enzyme activity and then encounters an organophosphate, pyrethroid, or in-hive miticide, her ability to break down that compound is impaired. The effective toxicity of the second compound rises, sometimes dramatically.

Johnson and colleagues (2013) documented striking interactions: sterol-biosynthesis-inhibiting fungicides such as prochloraz, which block the bees' P450 detoxification enzymes, sharply increased the toxicity of the in-hive miticides tau-fluvalinate and coumaphos, and similar synergy is well documented between these fungicides and pyrethroid insecticides. The mechanism is P450 inhibition. The same interaction applies to the beekeeper's own treatments: colonies that have been gathering fungicide-contaminated pollen may be more sensitive to tau-fluvalinate, coumaphos or other P450-detoxified compounds (oxalic acid is not detoxified this way).

This synergy matters particularly in crops that require fungicide protection during flowering – blueberries, cucurbits, apples, strawberries, and others – because the timing constraint for disease management overrides the beekeeper-friendly preference for off-bloom applications. Bees collecting in those crops during bloom are routinely accumulating fungicide residues. Chlorothalonil has been found at among the highest concentrations in bee bread of any agricultural chemical, and its presence correlates in survey data with increased pathogen susceptibility in the colonies carrying it.

The practical implication for grower-beekeeper conversations: ask about tank mixes and ask specifically about fungicides. A grower who would never apply an insecticide to a blooming crop while bees are present may not realize that the fungicide application on the same timing carries a bee hazard through a different mechanism.

15.5 Beeswax as a Pesticide Sink

Beeswax is not an inert structural material. It is a lipophilic medium – fat-soluble compounds partition into it readily and exit it slowly. Surveys of commercial beeswax in the United States, most notably the Mullin et al. (2010) analysis of wax and pollen from colonies across 23 states, found pesticide residues in virtually every sample, with miticides applied by beekeepers themselves accounting for some of the highest concentrations and most consistent detections.

Coumaphos (the active ingredient in CheckMite+ strips) and tau-fluvalinate (Apistan) were detected in a very high proportion of commercial wax samples. This is the natural consequence of using lipophilic compounds in the wax matrix of the hive: the compound absorbs into the wax during treatment and slowly releases back into the hive environment thereafter. After repeated treatments, the wax builds up a reservoir that continues to release compound between treatments and across seasons.

The commercial wax supply amplifies this problem. Commercial beeswax foundation is manufactured from pooled recycled wax collected from many beekeeping operations. Residues present in wax from a single operation that used miticides intensively can end up distributed across foundation sold to operations that never applied those compounds. A beekeeper who draws sheets of premium commercial foundation and prides himself on minimal chemical use may be housing his bees in comb that carries miticide residues from a dozen unknown sources.

The biological consequence that matters most is sublethal effects on queens and drones. Research has shown that exposure to coumaphos at concentrations found in commercial beeswax can reduce queen reproductive output and reduce drone sperm viability. For a queen producer or a drone breeder, comb quality is a production variable, not just an aesthetic one. The practical responses are comb rotation –

removing and replacing old dark comb on a regular schedule, which limits the time residues have to accumulate – and, where the stakes are highest, using foundation made from tested wax or from the operation's own cappings wax, which at least confines the residue burden to known sources.

15.6 Reading a Pesticide Label: The Legal Foundation

The pesticide label is a federal legal document. Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), applying a pesticide in a manner inconsistent with its label is a federal violation. This is not a guideline or a best-practice recommendation: it is the law. The label's mandatory pollinator protection statements carry the same legal force as every other restriction the label imposes on the applicator.

Pollinator protection language on current labels takes several forms. Some labels include a Bee Advisory Box, an EPA-designed icon and text block that explains exposure routes and mitigation. The box itself is advisory; the binding restrictions are the mandatory statements in the Directions for Use, such as "do not apply to blooming, pollen-shedding, or nectar-producing parts of plants if bees may forage on the treatment area" or "do not apply when bees are actively foraging." Some labels specify timing explicitly: "apply in the early morning or evening when bees are less active."

A beekeeper advising a grower, or a grower looking for guidance, needs to understand that compliance with the mandatory statements is not negotiable. Applying a product contrary to its mandatory bee hazard directions is a FIFRA violation, subject to civil and criminal penalties, regardless of whether any bee mortality is actually documented. The protection the mandatory statements provide is therefore legally real, not merely aspirational.

One label feature that beekeepers frequently misread is the signal word. Labels carry one of three signal words based on mammalian toxicity: DANGER for the most acutely hazardous products (with POISON and a skull and crossbones when the classification rests on oral, dermal or inhalation toxicity), WARNING for moderately hazardous products, and CAUTION for lesser acute hazard. These categories describe risk to the person handling the compound, not risk to bees. A compound labeled CAUTION can be acutely lethal to bees at field application rates, and a DANGER-labeled compound may pose relatively modest bee risk. Reading the signal word as a bee toxicity indicator is a common and consequential mistake.

Restricted-use pesticides (RUPs) carry an additional designation: only certified pesticide applicators (or persons under their direct supervision) may purchase and apply them. Products are classified restricted use mainly because of acute or chronic human toxicity or hazards to non-target organisms, and many highly bee-toxic compounds are in this category. The RUP designation is not itself a signal about bee hazard – it signals that the compound requires a trained applicator – but the overlap between highly bee-toxic compounds and RUPs means that a beekeeper investigating a kill should determine whether the suspect application involved an RUP and whether the applicator was properly certified.

15.7 Interpreting Residue Data: The Hazard Quotient

Modern analytical chemistry can detect pesticide residues at concentrations far below any biologically meaningful level. A gas chromatography/mass spectrometry analysis of pollen, wax, or honey can

routinely identify compounds at parts per billion or parts per trillion. This capability is valuable, but it creates a risk of misinterpretation: any detected residue, no matter how small, can be described as contamination, and contamination implies harm. Neither step in that logic chain is necessarily correct.

Detection reports that a compound is present above the analytical detection limit. It says nothing about whether that concentration is sufficient to produce a biological effect. To determine that, you need both the measured concentration and the relevant toxicological reference point for that compound: an LD50 for acute effects, a no-observed-effect concentration (NOEC) for chronic effects. The concept that formalizes this comparison is the **hazard quotient**: residue concentration divided by the appropriate toxicological benchmark. In pollen studies it is usually calculated as ppb divided by the LD50 in micrograms per bee, and results are compared with screening levels (for example 50 or 500 in Stoner and Eitzer) rather than a single pass/fail value. In regulatory risk assessment, a risk quotient is compared with a Level of Concern (for example 0.4 for acute risk to bees). Either way it is a screening tool, not proof of safety or harm. Where multiple compounds are present, the hazard quotients can be summed to estimate cumulative hazard, though this approach has limitations where compounds interact synergistically rather than additively.

The practical lesson for the beekeeper is to resist two equally mistaken responses to a residue report. The first mistake is to dismiss any detection as irrelevant on the grounds that modern methods detect everything. The second mistake is to treat any detection as proof of harm. Large-scale residue surveys of pollen and wax from apiaries across the United States have shown that the compounds detected most frequently are not always those contributing most to estimated hazard – the toxicity factor is as important as the concentration factor, and both are required for a meaningful interpretation.

A beekeeper who receives or commissions a residue analysis of pollen or wax from a suspect colony should ask not only “what was detected?” but “at what concentration, and how does that compare to the toxicity threshold for that compound?” Without that second part of the question, the first part cannot support a conclusion about harm.

15.8 Documenting and Investigating a Suspected Pesticide Kill

15.8.1 Recognizing an Acute Kill

The acute pesticide kill has a characteristic presentation: a large number of dead and dying bees accumulate at the entrance and on the landing board over a period of hours to days, the dead bees are predominantly foragers (adult bees in flight-ready condition, not young bees or bees with developing glands), and the event follows within 24 to 48 hours of an application in the foraging range of the colony. The pile may include bees that are still alive but moving abnormally – spinning, tremoring, or crawling without coordinated purpose.

The nature of the affected bees is a useful diagnostic feature. A mass of dead foragers with no dead brood suggests an exposure event that hit bees in the field or on their return, not a colony-wide poison that entered the food stores. A large kill of nurse bees or a pile of dead bees of all ages is more consistent with a contaminated food source that the whole colony consumed.

Organophosphate or carbamate poisoning produces the most dramatic acute presentation: the extended proboscis (tongue-out posture from uncontrolled proboscis muscle contraction), visible tremors, paralysis of the legs, and rapid death. This picture is strongly suggestive of AChE inhibition but is not pathognomonic: chronic bee paralysis virus and certain bacterial hemolymph infections produce superficially similar adult mortality with abnormal behavior. The field observation should prompt sample collection and formal investigation, not a firm diagnosis.

Pyrethroid poisoning produces similar acute mortality with neurological signs but without the same degree of proboscis extension. The kill pattern is similar, though the speed of death may differ depending on dose.

15.8.2 Recognizing Sublethal and Chronic Problems

The chronic or sublethal pesticide problem presents differently and is far harder to attribute. Reduced foraging intensity may be the first notice – the colony that was bringing in pollen last week seems less active this week, with fewer foragers departing and fewer returning. Navigation impairment appears as foragers that leave but do not return, producing a slow loss of forager population without the dramatic die-off at the entrance. This forager loss is indistinguishable from field predation by robins or flickers at the level of casual observation.

As forager loss continues, the colony loses its nutrient intake. Brood rearing declines, the population balance shifts toward young bees, and the colony appears weak for its season. Queen problems emerge from reproductive impairment: spotty brood, increased supersedure, queens that are present but underperforming. The beekeeper correctly identifies these as colony health problems but may not connect them to pesticide exposure because there was no kill event to remember.

The honest answer is that these signs are non-specific: every one of them is also produced by Varroa, by nutritional stress, by queen events, and by disease. Pesticide exposure is one item on a differential, not the default conclusion.

15.8.3 Procedure for Documenting a Kill

Speed and completeness are the two requirements. Residues in dead bees degrade at different rates – malathion and some carbamates break down within 24 to 48 hours in bee tissue – so a sample taken three days after a kill may contain undetectable concentrations of the compound that killed those bees. The beekeeper who waits a week to report a suspected kill may be waiting too long to support a formal investigation.

The correct sequence:

- **Photograph the scene immediately.** Photograph the entrance pile, the bottom board, any affected colonies, and the surrounding landscape including visible crops and roadsides. Photographs cannot be un-taken; they are the permanent record of what was present before the scene changed.
- **Record all circumstances.** Date, time, weather (temperature, wind direction and speed, recent rain), visible nearby activity (sprayer in a field, crop duster visible), and observations about the bees (behavior, age distribution of dead bees, condition of the hive interior).

- **Collect dead bees promptly.** The target is several hundred bees per affected colony, taken from the ground in front of the hive and from the bottom board. Place them in a clean container – a zip-closure plastic bag or a glass jar – with no added preservative. Freeze them as quickly as possible and keep them frozen. Freezing halts enzymatic degradation and preserves the residue profile that analytical chemistry will later interrogate. Do not use formalin or alcohol unless the receiving laboratory specifically directs it; these solvents remove the residues you are trying to preserve.

- **Collect supplementary samples where relevant.** Comb with pollen or beebread from the affected hive, plant material from the suspected source (leaves, flowers, or collected pollen), and any spray tank residue or product containers if accessible.

- **Notify the appropriate authorities.** Contact the state apiary inspector and the state lead pesticide agency (in most southeastern states this is the state department of agriculture). These agencies have formal investigation protocols, chain-of-custody requirements, and in some cases contracted laboratories. Sending samples to a commercial laboratory without following the state agency's chain-of-custody process may produce valid analytical results but will not support any formal determination or enforcement action.

- **Try to determine what was applied.** If a nearby grower or applicator is known or suspected, note their identity and the date of observed activity. Do not accuse; gather information. The application record, if obtained through a formal process, is essential evidence.

The two most common failures in pesticide kill investigations are delay (which allows residues to degrade past detectability) and non-reporting (which forecloses any formal process, limits what future investigations can build on, and means the incident never enters the epidemiological record on which regulatory decisions are made).

15.9 Grower-Beekeeper Communication: The Most Effective Tool

The best protection for a colony near agricultural land is a relationship with the people applying pesticides to that land. Everything else in this chapter – registration systems, label language, confinement protocols – is a fallback for situations where that relationship has not been built or has broken down.

15.9.1 What to Tell a Grower

A grower planning an insecticide application near an apiary needs guidance that is practical, specific, and consistent with what the law already requires. The elements of sound risk mitigation are:

Label compliance. This is not optional. Every mandatory pollinator protection statement in the label's Directions for Use is a legal requirement. Registration of a product for use on a given crop does not confer permission to ignore the label's bee hazard language; it confers permission to use the product subject to all label requirements including those statements.

Timing. Night applications dramatically reduce acute bee kill because foragers are in the hive. The practical window is typically after dusk until about two hours before sunrise, long enough for contact compounds on foliage to dry and degrade before foragers return. Systemic compounds are not fully

addressed by timing – residues in pollen and nectar persist regardless of when they were applied – but timing still reduces the acute exposure from spray contact.

Product selection. Where multiple products would achieve the grower's pest management objective, the lower-toxicity option for bees is worth preferring. In some cases, a product with a slightly different mode of action, longer residual, or granular formulation may provide equivalent pest control with lower bee risk. The beekeeper who can discuss modes of action with a grower is more persuasive than the beekeeper who only says "please don't spray."

Drift management. Buffer distances, nozzle selection, application pressure, and wind conditions all affect drift. Most labels specify wind speed limits and buffer requirements; compliance with these provisions also limits drift onto apiary sites.

Tank mix disclosure. The beekeeper needs to know about everything in the spray tank, not just the listed pest management target. Adjuvants, stickers, and fungicides added to a mix can interact with the insecticide and change its toxicity profile in ways the label for the insecticide alone does not contemplate.

Advance notification. This is the item that matters most from the beekeeper's perspective. Moving colonies out of the area before a daytime application eliminates the exposure entirely. Closing colonies in the southeastern US summer heat is a genuine hazard: a closed colony on a warm day can overheat fatally within a few hours, and a colony sealed for a full day in summer is at serious risk. Advance notification, ideally several days before the application, gives the beekeeper the opportunity to move rather than confine.

15.9.2 When You Receive Notification

If a grower notifies you of an upcoming application, the hierarchy of responses is:

- Move the colonies if the apiary can be relocated within a day's work.
- If movement is not practical, negotiate for timing, product, and drift management.
- If confinement is unavoidable, close the entrance as briefly as possible, add maximum ventilation (screen bottom boards fully open, upper ventilation added if possible), provide water inside the hive or at the entrance, and monitor for overheating. If the ambient temperature is above 85 degrees F, confinement becomes dangerous within hours. Plastic sheeting over a closed hive in direct summer sun can kill a colony in under an hour. Shade helps; moving the colony in the early morning before the application and returning it that night is almost always the safer choice.

Confinement should be understood as a measure of last resort with real and underappreciated hazards. In the southeastern US, where summer temperatures routinely reach the low to mid 90s and heat builds rapidly in a closed box, the risk of killing the colony through overheating is not theoretical.

15.10 Apiary Registration: What It Does and What It Cannot Do

Registration systems place apiary locations in a database accessible to growers, pesticide applicators, and public spray programs. When a grower or applicator consults the registry before an application, they learn whether bees are present within a given radius of the proposed treatment area and can contact the beekeeper to coordinate.

At the state level, apiary registration ranges from mandatory (the beekeeper is required by state law to register all colonies, providing a complete coverage map) to voluntary (the beekeeper can register but is not required to). At the county or district level, public mosquito control programs typically maintain their own notification lists; a beekeeper who registers with the county program receives advance notice of scheduled applications. At the national or multi-state level, voluntary online registries run by FieldWatch: BeeCheck, where beekeepers register apiary locations, and DriftWatch, where specialty-crop growers register sensitive fields (DriftWatch began as a university program and FieldWatch has been a nonprofit since 2012). Applicators can view both when planning operations.

The benefit of registration is real: a grower who knows an apiary is present can adjust timing, product, or buffer, and can notify the beekeeper before the application. This is far better than an unaware applicator treating a field adjacent to an unknown apiary. The benefit does not materialize unless both sides act on the system.

The limitations matter equally:

Participation is voluntary in most jurisdictions. A grower who does not consult the registry, or who is unaware that it exists, gains nothing from the beekeeper's registration. An applicator hired for a single season may not know the registry and may not be in the habit of checking it. Registration does not change the legal requirements the label imposes; it works through communication and goodwill, and those can fail.

Registration does not compel any particular practice. A grower who is aware of a registered apiary is not legally required to take any specific protective action simply because the beekeeper is in the registry. The label requirements are the binding constraint; the registry supports communication that may lead to voluntary protective measures beyond what the label requires, but it cannot substitute for label compliance.

Stale contact information defeats the system. A registration that lists an outdated phone number or email address provides no benefit when the grower attempts to notify the beekeeper. The beekeeper's obligation is to keep registration information current, which means updating it each season and whenever contact information changes.

Registration is a complement to direct personal relationships with neighboring growers, not a replacement. The beekeeper who registers with every available system and then does not know the name of the farmer growing corn a quarter-mile from the apiary has only half a plan.

15.11 Mosquito Control Programs

Organized mosquito control creates a specific exposure scenario that differs from agricultural applications in its operation, timing, and communication structure. Most adult mosquito control involves ultra-low-volume (ULV) applications of an adulticide – the organophosphates malathion and naled (both still in use, naled chiefly from aircraft) or synthetic pyrethroids such as permethrin, sumithrin and etofenprox (resmethrin products have been cancelled) – applied by truck or aircraft in the evening or at night because that is when adult mosquitoes are active.

The nighttime timing is the key protective factor for bees: foragers are in the hive, colony entrances present a much smaller target than the foraging range, and contact material has several hours to degrade before bees begin flying. This design is not coincidental – mosquito control programs have been aware of the bee kill potential of daytime OP applications since at least the 1970s, and nighttime scheduling is partly a response to that history. When programs are executed as designed, bee kills are uncommon.

Problems arise in three circumstances. First, emergency responses to flooding or storm damage often involve daytime aerial applications to areas where mosquito populations have exploded overnight; the emergency timeline overrides normal scheduling protocols. Second, some ground-based programs apply during early evening hours when bees are still active, particularly in summer when daylight extends past 8 PM. Third, programs that do not know an apiary is present may apply closer to an unregistered location than they would to a registered one.

The practical response is registration. Most county or district mosquito control programs maintain their own beekeeper contact list separately from state apiary registries, and registration provides both advance schedule notification and the ability to request a buffer around the apiary. In most programs, a known apiary receives either a buffer distance from the application area or prior contact giving the beekeeper time to close colonies before the truck passes. An unregistered apiary in the path of a scheduled application receives no such accommodation – not because the program is indifferent, but because they do not know the apiary is there.

Registration with the county or district program is therefore the single most effective protective step a beekeeper in a mosquito control district can take. Moving colonies permanently indoors for the mosquito season is not practical; assuming the risk is negligible is unwarranted; coating hive exteriors addresses none of the real exposure routes. Registration and a working relationship with the program coordinator is the defensible answer.

15.12 The Hazard Quotient in Practice: Residue Surveys and What They Show

The largest systematic survey of pesticide residues in US bee colonies was conducted by Mullin et al. and published in 2010, analyzing wax and pollen samples from 23 states. The survey found 121 different pesticides and metabolites in the samples. The most frequently detected compounds were the beekeeper-applied miticides – coumaphos and tau-fluvalinate – and fungicides including chlorothalonil.

Neonicotinoids and organophosphates were detected at lower frequencies but at concentrations more variable by location and season.

A follow-up analysis by Stoner and Eitzer (2013) examined pollen trapped from honey bee colonies at five Connecticut apiaries and detected 60 pesticides and metabolites. The most frequent detections were insecticides and acaricides (coumaphos, carbaryl, phosmet), alongside the fungicide carbendazim and the herbicide atrazine, but the highest hazard quotients belonged almost entirely to insecticides (phosmet, imidacloprid, indoxacarb, chlorpyrifos, fipronil, thiamethoxam). Atrazine and carbendazim were frequent but low in hazard. The comparison of the two surveys illustrates a critical point: the compounds you find most often in a residue survey are not necessarily the ones contributing most to bee hazard, and the compounds that contribute most hazard are not necessarily the ones present in the highest concentrations.

Traynor et al. (2016) followed 91 migratory colonies of three beekeepers along the US East Coast for about 300 days and found the highest pesticide burdens in colonies used for pollination; higher beebread and fungicide hazard quotients were associated with colonies that later died, and higher wax hazard quotients with queen events. Summed hazard quotients are a useful screening tool, though the authors note they likely underestimate risk because they ignore synergy.

The lesson for a beekeeper reading a residue report is to insist on quantitative interpretation: not just what was detected, but what hazard quotients those detections represent, and whether the cumulative estimate suggests a meaningful exposure burden. A list of detected compounds with no associated concentrations is not a risk assessment.

15.13 Chronic Exposure and the Problem of Attribution

A beekeeper observing gradual colony decline across an apiary located near intensive agriculture faces a genuine diagnostic challenge that has both technical and epistemic dimensions. The technical challenge is that chronic pesticide exposure produces non-specific effects: poor build-up, spotty brood, elevated supersedure rates, reduced foraging intensity, and colony loss. Every one of those effects is also produced by high Varroa load, Nosema, queen failure, nutritional stress, and poor management timing. There is no clinical sign that is specific to chronic low-dose pesticide exposure.

Establishing pesticide exposure as the cause rather than the context requires a systematic approach. Residue analysis of bee bread and wax from the affected operation, interpreted quantitatively against toxicity benchmarks using hazard quotients, documents whether exposure has occurred at biologically meaningful levels. This is necessary but not sufficient: exposure demonstrates that the compound was present at a potentially harmful concentration, but not that the observed effects are caused by that exposure rather than by the alternatives.

The alternatives must be evaluated seriously, not perfunctorily. Varroa and virus load should be measured directly with an alcohol wash or CO2 roll; a guess is not a ruled-out alternative. Nosema should be confirmed or excluded by microscopy or PCR. Queen quality and queen history should be examined: a colony with a failing two-year-old queen in a year of poor mating conditions needs a different response than a colony with a current queen showing impaired laying from sub-lethal pesticide

effects. Nutritional landscape should be assessed: is the apiary surrounded by a monoculture landscape offering narrow and seasonally exhausted forage, or diverse and continuous bloom? Management factors including treatment timing and comb age should be reviewed.

Where resources permit, moving a subset of colonies to a contrasting landscape for a comparative period is the closest thing available to a natural experiment: if colonies moved to a low-pesticide environment recover at a rate inconsistent with the Varroa, pathogen, and nutritional explanation, that adds weight to the pesticide hypothesis. If they do not recover, the alternatives need another look.

The honest position – and the one the exam will reward – is that a beekeeper can document exposure and can systematically rule alternatives in or out, but cannot assert causation from a pattern of non-specific decline alone. Overstating such a case, presenting suggestive correlations as established causation, damages the beekeeper's credibility in future conversations with growers, regulators, and the public. The beekeeper who speaks with precision about what the evidence does and does not support is a more effective advocate than one who claims certainty the evidence cannot support.

15.14 Environmental Stressors Beyond Chemical Pesticides

15.14.1 Nutritional Stress and Landscape Simplification

Modern agricultural landscapes in the coastal plain and piedmont of the southeastern US have become progressively simpler in their floral composition. Hedgerows have been removed, field margins mowed, and cover crops standardized to single species. The resulting landscape provides forage, but forage of reduced diversity. Pollen from a single plant species, even one that is adequate in quantity, may be deficient in one or more essential amino acids. Bees are known to self-regulate protein intake by collecting pollen from multiple species, and landscapes that limit this opportunity may constrain the nutritional quality of bee bread even where pollen quantity seems adequate. Colonies on extended monoculture forage – sustained periods on cotton or soybeans with no supplemental forage access – show measurable physiological stress.

The nutritional stress effect interacts with pesticide exposure: nutritionally compromised bees have reduced capacity to express detoxification enzymes, reduced immune function, and reduced resilience to all categories of stressor. The beekeeper assessing a colony in decline needs to know not only what pesticides were nearby but what the bees were eating.

15.14.2 Water Contamination

Bees are reliable collectors of standing water, particularly in the early morning when guttation droplets are available and before evapotranspiration removes surface moisture. Puddles at field margins, drainage channels receiving runoff from treated fields, and irrigation return-flow ditches are all potential routes for pesticide and herbicide residues to enter the colony via the water-collecting bees. Herbicide residues in water sources at concentrations well below phytotoxic levels may nonetheless affect bees. Providing a reliable, clean water source within the apiary – closer than the attractive but contaminated field margin puddle – is a partial mitigation.

15.14.3 Electromagnetic Sensitivity Claims

Repeated claims have circulated in popular beekeeping writing that colony navigation and health are disrupted by electromagnetic fields from cell towers, high-voltage power lines, or wireless devices. The experimental literature does not support these claims at the intensities present in real field conditions. Some laboratory experiments have documented effects of electromagnetic fields on bee behavior under exposure conditions far exceeding anything present in the environment near commercial wireless infrastructure. The gap between laboratory exposure intensity and field-realistic exposure makes these results poor predictors of real-world effects. Master-level candidates should be aware of this question and should know the current state of the evidence: there is no reliable evidence that commercially operating wireless infrastructure causes bee navigation failure or colony decline at real-world exposure levels; the few positive laboratory findings used unrealistic or poorly controlled exposures.

15.14.4 Occupational Heat Hazard

Environmental stress in beekeeping is not exclusively a bee problem. Summer beekeeping in the southeastern US involves sustained heavy-exertion outdoor work in temperatures routinely above 90 degrees F, often wearing a full suit and veil that reduces evaporative cooling. Heat illness – ranging from heat cramps and heat exhaustion through heat stroke – is a genuine occupational hazard for beekeepers. The symptoms of progressing heat illness (confusion, reduced coordination, cessation of sweating in a hot environment) are not always recognized as medical emergencies by the person experiencing them. Scheduling intensive colony work for early morning, maintaining hydration, and knowing the progression of heat illness symptoms are practical management obligations for anyone managing substantial colony numbers through a southern summer.

15.15 Seasonal Vulnerability Windows in the Southeastern US

The southeastern agricultural calendar overlaps with bee colony development in ways that create predictable high-risk periods.

Spring is the maximum-risk season. Fruit tree, blueberry, and bramble bloom coincides with peak colony forager populations and with intensive spring pesticide programs for fire ants, caterpillars, and early-season pest management. Colonies are at their largest foraging radius and most aggressive about resource collection. An acute kill in early spring, before the first honey production season, can eliminate the economic value of a colony's entire year. The combination of large forager populations, high food demand, and maximum pesticide application rate makes spring bloom the period warranting the most active communication with neighboring growers.

Summer brings a different risk profile. Cotton, soybeans, and intensive vegetable production in the coastal plain operate under sustained pest management programs through July and August. Summer dearth conditions – the period when spring bloom ends and fall blooms have not yet begun – push foragers farther from the apiary in search of resources, increasing contact with treated agricultural areas that the beekeeper may not even be aware of at the usual foraging radius. A colony under nutritional stress from summer dearth is also more vulnerable to the immunosuppressive effects of pesticide exposure.

Fall introduces some exposure patterns specific to the season. Late vegetable crops and fall cover crops may receive pesticide treatments extending into October. Dicamba drift – the post-application movement of volatile dicamba formulations from treated soybean fields (over-the-top registrations have been vacated and reissued more than once; check current status) – can damage or kill wildflowers and weeds in field margins and hedgerows, reducing the fall forage on which colonies depend for winter provisioning. The reduction in fall forage from herbicide drift is a nutritional stressor, not a direct pesticide kill, but its consequences extend through the winter as colonies enter with insufficient stores.

15.16 Numbers to Know Cold

Figure	Value	Why it is that value
LD50 classification: highly toxic	Below 2 micrograms per bee	Established toxicology category; many OPs and pyrethroids fall here
LD50 classification: moderately toxic	2.0 to 10.99 micrograms per bee	Middle category used by EPA for risk assessment tiering
LD50 classification: practically nontoxic	11 micrograms per bee or more	Most herbicides and fungicides land here for adult bees
Time window for acute kill evidence	24 to 48 hours after application	When forager mortality peaks; later sampling risks degradation of residues
Sample size for kill investigation	Several hundred bees per colony	Minimum needed for analytical sensitivity and statistical adequacy
Sample preservation temperature	Frozen (-18 degrees C or colder)	Halts enzymatic degradation of pesticide residues in bee tissue
Malathion degradation in bee tissue	24 to 48 hours	Fast-degrading OP; delay in sampling produces false-negative results
Tau-fluvalinate (Apistan) LD50	0.2 micrograms per bee (contact) in EPA's 2005 regulatory data; published laboratory values run far higher, roughly 9 to 16 micrograms per bee	The spread is why in-hive safety rests on the strip formulation and the bees' detoxification capacity, not on a single number
Hazard quotient screening levels	Pollen HQ screening levels of 50 and 500 (Stoner and Eitzer); EPA acute Level of Concern 0.4	Screening ratio of residue to toxicity benchmark; thresholds depend on the method and are not safety limits
Neonicotinoid EU outdoor ban year	2018	Clothianidin, imidacloprid, thiamethoxam banned for outdoor use; regulatory contrast with US
Coumaphos detection in commercial wax	High proportion of commercial US wax (Mullin 2010 survey)	Lipophilic compound partitions strongly into wax; persists across comb recycling

Figure	Value	Why it is that value
Guttation fluid neonicotinoid concentration	Can reach mg/L levels — up to about 346 mg/L imidacloprid and 102 mg/L clothianidin documented in treated corn, several orders of magnitude above soil-water concentration	Vascular concentration exceeds soil-water concentration; early-morning collection by bees
Clothianidin soil persistence	Multiple growing seasons detectable	Explains detection in wildflowers years after last field treatment
Confinement overheating risk in southeastern US summer	Within hours at above 85 degrees F ambient	Closed colony cannot cool itself; plastic sheeting in sun kills in under an hour

15.17 Common Misconceptions

Misconception: Closing the colony during a spray application is sufficient to protect bees from pesticide exposure. **Correction:** Closure prevents contact with the spray itself, but bees foraging before and after the closure window collect contaminated pollen and nectar that enters the food stores. Nurse bees and brood are exposed through consumption of that contaminated food for weeks after the application event. Closure also creates a heat hazard in summer. The goal must be to reduce total exposure across the season, not to interrupt a single application event.

Misconception: Systemic insecticides can be safely used on crops if the application is timed to avoid bloom. **Correction:** Systemic compounds enter plant vascular tissue and appear in pollen and nectar regardless of when the surface was treated. A seed treatment applied before the plant emerges is present in the plant's pollen when it blooms weeks later. Timing an application away from bloom does not prevent bees from consuming the compound in the plant's pollen and nectar.

Misconception: The signal word on a pesticide label (DANGER, WARNING, CAUTION) indicates the compound's toxicity to bees. **Correction:** Signal words classify acute mammalian toxicity to the applicator, not bee toxicity. A CAUTION-labeled compound can be acutely lethal to bees at normal application rates. A DANGER-labeled compound may present lower bee risk than a CAUTION-labeled one with higher bee toxicity. Bee hazard must be assessed from the pollinator protection statements and the bee hazard classification on the label, not from the signal word.

Misconception: Any pesticide residue detected in pollen, wax, or honey is evidence of harm to the colony. **Correction:** Detection reports that a compound is present above the analytical detection limit. Modern methods detect compounds at parts per billion or lower. Whether a detected concentration is biologically meaningful requires calculation of a hazard quotient: the detected concentration divided by the appropriate toxicity benchmark. Detection without concentration and without a toxicity comparison is not a risk assessment.

Misconception: Fungicides don't harm bees, so they can be ignored in a tank mix discussion with a grower. **Correction:** Fungicides have low direct bee toxicity but can substantially increase the toxicity of

insecticides in the same tank mix or encountered shortly thereafter. Sterol-biosynthesis-inhibiting fungicides such as prochloraz inhibit P450 detoxification enzymes and strongly increase the toxicity of pyrethroids and organophosphates such as tau-fluvalinate and coumaphos; chlorothalonil has also been shown to increase tau-fluvalinate toxicity, possibly through the same P450 pathway. Bloom-time fungicide applications deserve the same attention from a bee-protection standpoint as insecticide applications, because the fungicide primes the colony for increased damage from any co-occurring insecticide.

Misconception: A colony with no dead-bee pile at the entrance has not experienced pesticide exposure. **Correction:** Sublethal and systemic pesticide exposures can produce profound effects on colony health without generating a dead-bee accumulation at the entrance. Navigation impairment causes foragers to fail to return, but they die in the field, not at the entrance. Learning and memory impairment reduces foraging efficiency but produces no dead bees. Reproductive effects on queens and drones are invisible at the entrance. The absence of a kill event is not evidence of the absence of exposure.

Misconception: Labeling restrictions on pesticide use near bees are voluntary guidelines that applicators may choose to follow. **Correction:** Mandatory pollinator protection statements in the Directions for Use of a federally registered pesticide label are legally binding under FIFRA; advisory text such as the Bee Advisory Box is not itself a use restriction. Applying a product in violation of its label is a federal offense, regardless of whether any bees are actually harmed and regardless of whether the product is otherwise registered for the crop and application rate.

Misconception: Restricted-use pesticide designation means the compound is especially dangerous to bees. **Correction:** Restricted-use status reflects primarily human toxicity (acute or chronic) and hazards to non-target organisms generally; it is not a bee toxicity classification. Some highly bee-toxic compounds are not RUPs, and some RUPs have relatively low bee toxicity. Bee hazard requires separate assessment from the bee hazard statements on the label.

Misconception: Apiary registration protects colonies by requiring growers to notify beekeepers before applying pesticides. **Correction:** Registration places apiary locations in a database that growers and applicators can consult. In most jurisdictions, participation by applicators is voluntary, and registration does not legally compel notification, a buffer distance, or any specific protective practice. Registration works through communication and goodwill. An applicator who does not check the registry, or who is unaware that it exists, is not bound by the beekeeper's registration entry.

Misconception: Bee bread residue analysis is unnecessary because the same compounds can be detected in dead bees following a kill. **Correction:** Bee bread residue analysis serves a different purpose from kill investigation. Bee bread accumulated over weeks or months reflects chronic low-level exposure that would not produce an acute kill event; it documents the colony's total dietary exposure to multiple compounds. Kill investigation focuses on the acute event and the compounds responsible; bee bread analysis addresses the chronic exposure question. Both are needed for a complete exposure picture, and neither substitutes for the other.

Misconception: Moving colonies out of an agricultural area eliminates their pesticide exposure. **Correction:** Moving colonies changes their exposure profile but does not guarantee elimination of

exposure. Pesticide residues already stored in the colony's wax and food stores remain present. Residues in commercial foundation brought in to replace comb may carry contamination from pooled recycled wax. And the destination site may have its own pesticide history. Movement is valuable, particularly as a comparison tool for investigating suspected chronic exposure, but it is not a clean slate.

Misconception: Miticide residues in beeswax are a concern only for the operation that applied them. **Correction:** Commercial beeswax foundation is manufactured from pooled recycled wax collected from many operations. Miticide residues present in wax from one operation are distributed through the commercial supply chain and can appear in foundation used by operations that never applied those compounds. A beekeeper purchasing commercial foundation is purchasing a product that may contain residues from unknown sources.

15.18 Self-Check Questions

- A grower plans to apply a neonicotinoid insecticide to a field of cucumbers three weeks before they bloom, reasoning that the compound will have dissipated by the time bees visit the flowers. Explain the flaw in this reasoning.
- Distinguish contact toxicity from systemic toxicity and explain why the distinction changes the risk management options available to both the beekeeper and the grower.
- A beekeeper discovers 500 dead bees at the entrance of three colonies on a Monday morning. She photographs the scene and plans to collect samples over the weekend. What is wrong with this plan, and what should she do instead?
- You receive a residue analysis report from a laboratory showing chlorothalonil detected at 45 parts per billion in a pollen sample from your apiary. A neighbor tells you this proves your bees are being poisoned. Explain what additional information you would need before you could evaluate that claim, and name the concept you would use.
- Explain why beeswax serves as a long-term pesticide reservoir, and describe two practical management responses available to a beekeeper concerned about wax contamination.
- Describe the clinical presentation of acute organophosphate poisoning in a honey bee colony, and name two other conditions that can produce superficially similar adult mortality.
- A beekeeper argues that she does not need to register her apiary with the county mosquito control program because mosquito adulticides are applied at rates too low to harm bees. Evaluate this argument.
- Explain the P450 synergy mechanism and describe how it applies to both agricultural fungicides and the beekeeper's own in-hive miticide treatments.
- Why is sublethal pesticide exposure harder to document as the cause of colony decline than an acute pesticide kill? Name three conditions that must be ruled out before pesticide exposure can be seriously considered as the primary cause.
- Describe what the hazard quotient is, how it is calculated, and which of two errors it is designed to help a beekeeper avoid.

- A neighbor beekeeper tells you that cell towers installed last year are causing navigation failure in his bees because he has read that electromagnetic fields disrupt bee orientation. What is the state of the experimental evidence on this question, and what is the most important alternative explanation you would want to investigate?

- Explain why advance notification from a grower before a pesticide application is more valuable than colony confinement, and describe the specific hazard that makes confinement dangerous in the southeastern US.

15.19 Self-Check Answers

- Neonicotinoids are systemic insecticides: the plant's vascular system takes up the active ingredient from the soil or seed treatment and distributes it into all plant tissues, including pollen and nectar. The compound is not on the surface of the plant where it would be subject to photodegradation and weathering; it is inside the pollen and nectar that bees will collect when the plant blooms. A three-week gap between soil or seed application and bloom does not remove the compound from plant tissue; it may reduce the concentration, but it does not eliminate exposure. This contrasts with a contact insecticide applied to the foliage, where timing an application several weeks before bloom allows surface residues to degrade. The systemic mechanism makes timing away from bloom insufficient as a protective measure for neonicotinoids.

- A contact insecticide affects bees only through direct exposure to the compound on plant surfaces, spray droplets, or contaminated dust. The exposure event is discrete in time: once the surface residue degrades, exposure ends. A beekeeper can reduce contact exposure by timing (avoiding applications when bees are flying), by placement (applications to field interiors rather than margins), and by product formulation. A systemic insecticide is taken up by the plant and present in pollen and nectar throughout the crop's bloom period, regardless of when the surface was treated. The risk management options narrow substantially: the grower cannot time away from bloom to protect bees, because the compound is in the pollen and nectar during bloom by design. The beekeeper's option is to move colonies away from the crop during bloom or to work with the grower to substitute a non-systemic alternative where one is available.

- Many insecticides, including malathion and the carbamates, degrade rapidly in bee tissue – some within 24 to 48 hours of death. A sample collected five to six days after the observed kill may contain no detectable residue of the compound responsible, producing a false-negative analytical result. The correct procedure is to act immediately: photograph the scene the morning the kill is discovered, collect several hundred freshly dead bees from in front of the hives in clean containers, and freeze the samples at the earliest opportunity. She should also contact the state apiary inspector and the state pesticide lead agency the same day, follow their chain-of- custody instructions, and record all circumstances including date, weather, and any observed spray activity in the area.

- Detection reports only that the compound is present above the laboratory's analytical detection limit, not that the detected concentration is sufficient to cause harm. To evaluate the claim, you need the concentration in units comparable to the relevant toxicological benchmark (for example, micrograms per gram of pollen), and you need the appropriate toxicity endpoint for chlorothalonil in the context of chronic dietary exposure (for example, a no-observed-effect concentration). The concept used to combine these two values is the hazard quotient: the

detected concentration divided by the toxicity benchmark. The result is then compared with the screening level or Level of Concern appropriate to the method; it is a screening tool, not proof of safety or harm. At 45 ppb, the chlorothalonil concentration would need to be compared against the relevant NOEC for dietary exposure to adult bees or to nurse bees to determine whether this represents a meaningful exposure.

- Beeswax is a lipophilic medium – fat-soluble compounds partition into it readily and exit slowly. When beekeepers apply lipophilic miticides (coumaphos, tau- fluvalinate) in the hive, the active ingredient is absorbed into the comb wax during treatment and continues to be released slowly into the hive environment for years afterward. Repeated treatments build up a reservoir that accumulates over multiple seasons. Two practical responses: first, comb rotation – removing and melting down old dark comb on a regular schedule limits the time residues have to accumulate and reduces the standing reservoir; second, using cappings-derived or residue-tested foundation for critical production areas, particularly in queen-rearing operations, limits the introduction of unknown residue burdens from commercial pooled wax.

- Acute organophosphate poisoning presents with rapid accumulation of dead and dying adult bees at the entrance, predominantly foragers. Living affected bees show tremors, leg paralysis, loss of coordinated movement, and the extended proboscis (tongue-out posture) that results from uncontrolled contraction of the proboscis muscles through the effect of accumulated acetylcholine at the nerve synapse. Death typically follows the neurological signs within minutes to hours. Two conditions that produce superficially similar adult mortality: chronic bee paralysis virus (CBPV), which produces shivering, hair loss, and progressive adult death with behavioral abnormality; and certain bacterial infections of the hemolymph, which can produce rapid adult mortality with some similar field signs. Both distinctions require either pathogen testing or residue analysis for resolution.

- The argument is incomplete in ways that matter. Mosquito adulticides do carry bee toxicity: malathion, historically the most widely used, is an organophosphate with high bee toxicity. The standard protocol of nighttime application does reduce risk substantially, but problems arise during emergency daytime aerial applications, early- evening applications, and applications where the program does not know an apiary is present. Registration solves the last problem: a registered apiary receives advance notification and may be given a buffer distance or asked to close colonies before the truck passes. An unregistered apiary receives no accommodation because the program does not know it exists. Claiming the risk is too low to warrant registration is also a decision that the program coordinator makes, not the beekeeper – and the beekeeper's leverage in that decision comes from being a registered participant.

- Cytochrome P450 monooxygenases are a family of enzymes bees use to metabolize and detoxify foreign compounds, including some insecticides. Many fungicides inhibit one or more P450 enzymes as a side effect of their fungicidal mechanism. A bee that has consumed fungicides inhibiting her P450 activity has reduced capacity to break down insecticides that would otherwise be cleared by those enzymes. The effective toxicity of the insecticide rises – the bee is poisoned at a dose that would have been sublethal if her detox enzymes were functioning normally. The same mechanism applies to in-hive miticides: colonies foraging in agricultural landscapes where fungicides are applied during bloom may have suppressed P450 activity, making them more sensitive to the next miticide treatment the beekeeper applies. This is why beekeeper-applied in-hive treatments should be evaluated against the background of what the colony has been foraging on.

- Sublethal exposure produces no discrete event – no kill pile, no datable application, nothing to photograph or sample within a critical time window. The effects are non-specific: impaired navigation, spotty brood, queen issues, poor build-up, reduced longevity. Each of these is also produced by high Varroa load (which must be measured directly and excluded, not assumed absent), by Nosema (which requires microscopy or PCR to confirm or exclude), and by queen failure from any cause (which requires queen history and direct evaluation). A fourth alternative is nutritional stress from a simplified foraging landscape. Establishing pesticide exposure as the cause rather than a co-occurring circumstance requires quantitative hazard quotient analysis of bee bread and wax, systematic exclusion of the major alternatives by direct measurement, and ideally a comparison with colonies moved to a contrasting environment.

- The hazard quotient (HQ) is the ratio of the measured residue concentration to the relevant toxicological benchmark for that compound: HQ = measured concentration / toxicity benchmark. In pollen studies it is usually ppb divided by the LD50 in micrograms per bee, and the result is compared with screening levels rather than a single pass/fail value; it is a screening tool, not proof of safety or harm. Where multiple compounds are present, HQs can be summed to estimate cumulative hazard. The concept is designed to prevent two opposite errors: dismissing any detection as biologically irrelevant simply because the compound is present at a low concentration (since a highly toxic compound at low concentration may still have a high HQ), and treating any detection as evidence of harm regardless of the concentration (since a low-toxicity compound at a high concentration may still have a low HQ). The HQ forces both pieces of information – concentration and toxicity – into the interpretation.

- The experimental evidence for electromagnetic field effects on bees under field- realistic conditions does not show a reliable effect that could serve as a practical explanation for navigation failure. Some laboratory experiments have documented effects of electromagnetic fields on bee behavior, but at exposure intensities far exceeding anything present near commercial wireless infrastructure. The gap between laboratory exposure levels and real environmental levels makes these results poor predictors of field effects. The most important alternative investigation would be a thorough Varroa assessment: high mite loads and associated deformed wing virus infection are the most common documented cause of forager loss and navigation failure in managed colonies, and mite-driven colony decline can present as a sudden increase in lost foragers if Varroa populations have grown rapidly. Other alternatives include queen status, nutritional landscape, and pesticide exposure from nearby agricultural operations.

- Advance notification gives the beekeeper time to move the colonies out of the area, which eliminates exposure entirely. Confinement – closing the colony during and after the application – reduces contact with the spray event but does not eliminate exposure from contaminated pollen and nectar collected before and after the closure. More critically, confinement creates a severe heat hazard in the southeastern US: a closed colony on a summer day with ambient temperatures above 85 to 90 degrees F cannot adequately cool itself, and the interior temperature can rise to lethal levels within hours. Plastic sheeting over a closed hive in direct summer sun can kill a colony in under an hour. The colony that survives the pesticide application but dies from heat stress is a failure no less complete than a direct pesticide kill, and it is entirely preventable by the simple step of having received advance notice and moving the colonies beforehand. The combination of effective notification and a cooperative working relationship with the grower is more valuable than any post-hoc protective measure.

15.20 Further Reading

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US Environmental Protection Agency. Pollinator Risk Assessment Guidance and Bee Advisory Box label requirements. Available at epa.gov. The EPA's current framework for pollinator protection in pesticide registration and label language.

Honey Bee Health Coalition. *Tools for Varroa Management.* 9th edition, June 2026. Although focused on Varroa, includes current information on miticide-wax interactions and integrated management approaches relevant to pesticide chapter.

University of Florida IFAS Extension. Publications on pesticide safety for beekeepers and Florida Managed Pollinator Protection Plan. Covers southeastern US-specific issues including mosquito control programs and citrus-related pesticide exposure.

University of Georgia Cooperative Extension. Apiary management publications and pesticide-bee interaction guidance; relevant particularly for coastal plain and piedmont beekeeping contexts.

Auburn University, Department of Entomology and Plant Pathology. Managed pollinator protection publications and colony loss survey methodology.

Chapter 16. Honey Chemistry, Production & Food Safety

Covers exam questions Q288-Q308.

16.1 Orientation

Honey is the product that most people associate most immediately with beekeeping, and it is also the product most vulnerable to mishandling, misrepresentation, and legal exposure. A working beekeeper can produce good honey by following rules of thumb; a master-level candidate needs to understand why those rules exist, because the exam is built on the mechanisms, not the recipes. The three ideas that organize everything else in this chapter are: composition determines behavior, temperature is the critical process variable, and the legal framework is more demanding than most small producers realize.

Composition determines behavior because honey's physical properties — how it flows, whether it granulates, whether it ferments, whether it resists microorganisms — all follow directly from what is in it and in what proportions. The glucose-to-water ratio is the best simple predictor of granulation rate, although nuclei, viscosity and storage temperature modify the result. The water content, measured carefully and corrected for temperature, predicts fermentation risk. The enzyme content tells you how the honey was handled after harvest. None of these relationships are arbitrary; each has a physical or biochemical mechanism, and the exam probes those mechanisms.

Temperature is the critical process variable because honey is thermolabile in ways that matter commercially and legally. Every step from harvesting supers to the finished jar on a shelf involves decisions about heat, and those decisions affect enzyme activity, HMF accumulation, granulation behavior, moisture content, color, and flavor. Getting temperature management right is what separates a marketable product from a degraded one.

The legal framework matters because honey labeling and safety obligations are more specific, more layered, and more consequential than beekeepers often appreciate. Federal food law is mandatory and applies to anyone selling honey in interstate commerce; FDA guidance interprets it; voluntary USDA grade standards sit alongside it; and state requirements sit on top. The examiner expects a master-level candidate to hold all of this clearly and to know which obligations are discretionary and which are not.

16.2 Sugar Composition and Its Consequences

Honey is principally a concentrated sugar solution. Fructose and glucose together account for roughly 70 percent of honey by weight — fructose at approximately 38 percent and glucose at approximately 31 percent — with the remainder made up of water (17-20 percent in properly ripened honey), minor sugars, acids, enzymes, minerals, and volatile compounds. The minor sugars include sucrose, maltose, turanose, kojibiose, and others, each present in small amounts and most of them products of enzymatic and acid-catalyzed transformations in the hive.

Glucose content, and especially the glucose-to-water ratio, is the most practically important compositional figure for a producer, because glucose is the sugar that crystallizes. Glucose

monohydrate, not fructose, is the crystal form that constitutes granulated honey. A honey with a glucose-to-water ratio above about 2.0 will granulate quickly, and one below about 1.7 granulates slowly; a high fructose-to-glucose ratio (above about 1.3) also slows granulation, and such a honey can remain liquid for months or years. Canola honey, in which the glucose fraction is high relative to fructose, can granulate in the comb before it is extracted if harvest is delayed. Tupelo honey, with its exceptional fructose dominance, is prized precisely because it resists granulation. The ratio between the two is set by the floral source and cannot meaningfully be altered by the beekeeper.

Sucrose is normally present in only trace amounts in finished honey, because the bee's primary processing enzyme, invertase (also called sucrase), hydrolyzes sucrose into its component monosaccharides — fructose and glucose — during ripening. Bees add invertase from their hypopharyngeal glands as they work the nectar into the cells. Ripening is not instantaneous: the conversion continues during the drying process, which is why freshly deposited nectar tests high in sucrose and properly ripened honey does not. An elevated sucrose level in finished honey is therefore diagnostically significant. It can indicate that the honey was extracted prematurely, before ripening was complete, or it can indicate adulteration with sucrose-based syrups that were not adequately inverted. The Codex Alimentarius standard sets a sucrose maximum of 5 percent for most honeys, with some exception for specific varieties. Knowing this helps the examiner distinguish a beekeeper who understands invertase from one who simply knows that sucrose is present.

16.3 Water: The Master Variable

Water is honey's most consequential constituent after the sugars, and measuring it accurately is among the most practically important skills a producer can have. All of the critical quality thresholds in honey — the fermentation threshold, the grade limits, the specification a wholesale buyer will accept — are defined in terms of water content.

16.3.1 The Refractometer and Why Temperature Matters

A honey refractometer measures the refractive index of a thin film of honey on the prism and converts the reading to a sugar or moisture content. The instrument works because light bends more sharply as the concentration of dissolved sugars increases, and this bending is precisely quantifiable. The problem is that the refractive index of a sugar solution also varies with temperature: a warm sample bends light differently from a cool sample of identical composition. If the honey and the refractometer are not at the same temperature — and ideally both at the instrument's calibration temperature, typically 68 degrees F — the reading will be wrong. A warm sample in a cool instrument will overstate moisture; a cool sample in a warm instrument will understate it.

The practical correction is straightforward: let both sample and instrument sit in the work area until they reach the ambient temperature, check that temperature against the calibration range printed on the instrument, and apply a correction factor if the temperature differs from calibration. Some refractometers have built-in temperature compensation; many do not. The other procedural discipline that matters is testing individual tanks or individual supers rather than composites: one wet super can

raise an entire tank's moisture above specification, and testing only the composite misses the contribution of that one outlying batch until it is too late.

16.3.2 Grade Limits and the Fermentation Threshold

The United States Standards for Grades of Extracted Honey, published by USDA AMS, set a maximum moisture of 18.6 percent for Grade A honey (Grade C allows up to 20 percent). The Codex Alimentarius Standard for Honey (CXS 12-1981) separately sets a general moisture limit of 20 percent — a looser threshold than the USDA Grade A standard, not the same one. These are commercial and regulatory thresholds designed to exclude honey that is obviously too wet to keep in trade.

The fermentation threshold is a different number. Osmophilic yeasts — principally species of *Zygosaccharomyces* — are present in virtually all honey in small numbers, having been introduced from the nectar itself, from the beekeeper's equipment, and from the environment. Under normal conditions, the water activity of honey (roughly 0.5-0.6) is too low for these yeasts to reproduce at a rate that causes spoilage. As moisture rises above about 17 to 17.5 percent, water activity approaches the range (about 0.61) where yeast reproduction becomes viable and fermentation can occur, especially if the honey is held at warm temperatures. Below 17-17.5 percent, fermentation is essentially impossible regardless of yeast load. In the range between roughly 17.5 and 19 percent, the risk is real but depends on yeast count and temperature.

The practical consequence is that a honey testing at 19 percent moisture fails Grade A, clears the Grade C limit by 1 percentage point, and is at meaningful fermentation risk — particularly if it is stored warm or if it begins to granulate. This is not a contradiction between the two standards; they measure different things. The grade standard is a commercial boundary; the fermentation threshold is a microbiological one. The beekeeper who understands both can manage accordingly: honey at 19 percent is not unsalable, but it needs to be treated as a product with a known vulnerability.

16.3.3 The Partial Granulation Problem

One mechanism that the exam explicitly tests is the interaction between granulation and fermentation. When honey begins to granulate, the glucose that crystallizes out is essentially removed from the liquid phase as a solid. The remaining liquid therefore has a higher water content than the bulk honey did before granulation began. If the initial moisture was 19 percent, partial granulation can raise the liquid phase by roughly 1.5 to 3 percentage points, to about 20.5 to 22 percent — enough to cross the fermentation threshold. This is why honey that tested at acceptable moisture when bottled can arrive at a customer in a fermented state months later: it crossed the fermentation threshold after packing, not before. Catching this requires either bottling at consistently low moisture (below 18 percent provides a margin) or monitoring stored product for early signs of fermentation.

16.4 Enzymes and What They Tell You

Honey contains several enzymes derived from bee secretions and from the nectar itself. Their presence, activity, and degradation under heat make them both functionally important and diagnostically useful.

Invertase does the primary biochemical work of ripening: it cleaves sucrose into fructose and glucose. It is secreted by the hypopharyngeal glands and thoroughly mixed into the nectar during processing. High activity in finished honey reflects fresh processing; its level is not commonly measured as a quality indicator.

Glucose oxidase (GOX) catalyzes the oxidation of glucose to gluconic acid, with hydrogen peroxide (H_2O_2) as a byproduct. Gluconic acid is the dominant organic acid in honey, largely responsible for honey's pH of 3.2-4.5. The H_2O_2 is the most potent antimicrobial component in diluted honey, but it is essentially inactive in undiluted honey because GOX itself is inhibited at the high sugar concentrations of full-strength honey. When honey is diluted — as in a wound environment or a diluted honey solution — GOX becomes active and begins producing H_2O_2 continuously. This is a sensible adaptation: the bee produces an antimicrobial system that switches on when it is needed (honey diluted in water or body fluids) and is quiescent in the concentrated product in storage. Some nectar sources contain high catalase, which degrades H_2O_2 and reduces this antimicrobial contribution; manuka honey compensates with methylglyoxal (MGO), a non-peroxide antimicrobial that forms in the honey from dihydroxyacetone, which *Leptospermum* nectars carry in abundance.

Diastase (amylase) breaks down starch chains. Its biological role in honey is minor — honey contains little starch — but its heat sensitivity makes it a standard quality indicator. The diastase number (or Schade scale value) measures the rate at which a honey digests a standard starch substrate. Fresh, gently handled honey has a high diastase number; honey that has been overheated or stored warm has a lower one, because heat denatures the enzyme irreversibly. The Codex Alimentarius minimum for most honeys in international trade is a diastase number of 8, and 3 for honeys with a naturally low enzyme content. Some honeys of specific floral origins (citrus, for instance) are naturally low in diastase even when fresh, which is why the Codex makes provision for them and why the diastase number should be interpreted alongside HMF.

Catalase, mentioned above in the context of GOX, is primarily a nectar-source enzyme. It has no quality indicator role in standard honey analysis.

16.5 Antimicrobial Mechanisms

Honey resists microbial spoilage through a combination of mechanisms, no single one of which is solely responsible for its keeping quality.

Low water activity is the primary physical barrier. Honey's water activity of approximately 0.5-0.6 is too low for most bacteria, molds, and yeasts to reproduce. At this Aw, cellular water is so thoroughly bound by solute interaction that it is unavailable to support microbial growth. Only osmophilic organisms — those adapted to high-sugar environments — can tolerate this, and even they require that the moisture content be high enough for the water activity to rise slightly.

Low pH provides a chemical barrier. A pH of 3.2-4.5 inhibits many bacteria for which neutral or near-neutral conditions are required. Gluconic acid, as the dominant acid, is primarily responsible. This is not bactericidal across all contexts, but it substantially raises the challenge for any contaminating organism.

The hydrogen peroxide system provides a specific antimicrobial compound. As discussed above, this is active when honey is diluted and inactive when concentrated. Wound healing applications and throat preparations exploit this; the beekeeper in the honey house need only know that the H2O2 activity is irrelevant in sealed, undiluted product.

Phenolic compounds from the nectar and propolis contribute to antimicrobial activity through mechanisms independent of peroxide. These are plant-derived and vary with floral source. Manuka honey's methylglyoxal also acts independently of peroxide, although it is not a phenolic: it is not inhibited by catalase, so it remains active in some clinical contexts where H2O2 is degraded.

The critical caveat: honey is not sterile. It is microbially stable under most conditions, but it contains live organisms and dormant spores. Osmophilic yeasts are present in all honey; they are the agents of fermentation when moisture rises too high. Bacterial spores, including *Clostridium botulinum*, survive in honey indefinitely. They do not germinate and produce toxin in honey itself — the Aw is too low — but they represent a hazard in other contexts.

16.6 Infant Botulism

The advisory that honey should not be fed to infants under twelve months of age is grounded in a specific microbiological mechanism that every master-level beekeeper should be able to explain accurately. *Clostridium botulinum* spores are environmental — present in soil, dust, and plant material — and are introduced into honey through contact with the environment during production. No practical processing step excludes them. Heating honey sufficiently to destroy bacterial endospores would require temperatures that completely destroy the product.

In adults and older children, the gut is colonized by a mature microbial community that outcompetes *C. botulinum*; the spores pass through without germinating in significant numbers. The infant gut before approximately twelve months is immature and lacks this competitive microbial flora. *C. botulinum* spores that are ingested can germinate, colonize the intestine, and produce botulinum toxin *in situ*. This is infant botulism — a colonization disease, not a foodborne poisoning from preformed toxin. The distinction matters because it explains why even small exposures are risky (the infectious dose in infants is unknown, so no amount of honey is considered safe under twelve months) and why the mechanism is different from the botulism associated with improperly canned vegetables (where preformed toxin is ingested).

Honey is the one widely used food that carries a specific infant feeding restriction (it is the identified, avoidable source, though most infant botulism cases come from other environmental exposure to spores in soil and dust), and a producer selling at a farmers market or a retail shelf has both a practical and arguably a moral obligation to communicate it. Some states require the advisory on the label; federal law does not explicitly mandate it for honey, but a claim of "safe for all ages" on a label would likely constitute a false statement of material fact. The prudent course is to carry the warning regardless of whether it is compulsory in a given jurisdiction.

16.7 HMF, Heat Damage, and the Diastase Number

Hydroxymethylfurfural is one of the most important analytical markers in honey quality assessment, and understanding why it forms makes its significance clear.

16.7.1 How HMF Forms

HMF is produced by the acid-catalyzed dehydration of fructose. In honey's acidic environment (pH 3.2-4.5), fructose — the dominant sugar — undergoes slow dehydration at room temperature and much faster dehydration when heated. The reaction is irreversible: once HMF has formed, it does not convert back. Fresh honey from the comb contains essentially no HMF; the molecule accumulates with time and, dramatically, with temperature. HMF rises slowly at ambient temperature (a few mg/kg to roughly 20 mg/kg per year, faster in warm storage) and increases steeply with temperature: at 140 degrees F it climbs modestly over a day, but at 160-200 degrees F it can reach tens to hundreds of mg/kg within hours.

Certain adulterants — particularly commercial invert syrups made by acid hydrolysis of sucrose — already contain substantial HMF when they are added to honey, so elevated HMF can also indicate adulteration. This is why HMF is sometimes grouped with other adulteration markers even though its primary practical use is as an indicator of heat abuse and aging.

16.7.2 Standards and Thresholds

The Codex Alimentarius Standard for Honey sets a maximum of 40 mg/kg for most honey, with a higher limit of 80 mg/kg for honey produced in tropical or near-tropical regions, where ambient temperatures during storage and ripening are higher and some accumulation before export is unavoidable. USDA Grade standards do not set an explicit HMF limit, but HMF interacts with color grading (high HMF is associated with the darkening that accompanies heat damage) and with diastase.

16.7.3 Diastase as a Companion Indicator

Because some floral honeys are naturally low in diastase even when fresh and undamaged, Codex allows a lower diastase minimum of 3 Schade units for them, and analysts read diastase together with HMF (the EU adds an HMF limit of 15 mg/kg for the 3-unit allowance): a honey that fails the 8-unit minimum but has low HMF may qualify as a naturally low-diastase variety; one with both low diastase and elevated HMF has been heat-treated or is old. This paired assessment is more diagnostic than either measure alone, and the exam item asks for exactly this paired reasoning.

16.7.4 Honey House Practice

The implications for the honey house are specific. Honey should be warmed only enough to allow it to flow easily for bottling — generally no higher than 100-110 degrees F for most purposes, and briefly. Every degree above that and every additional minute of exposure adds to the HMF burden and removes enzyme activity irreversibly. Microwave warming is particularly problematic because it creates hot spots that locally exceed any safe temperature even when the bulk of the sample is within range. Repeated warming cycles — warming to bottle a batch, letting it cool, then warming again when demand resumes

— compound the damage cumulatively. Once enzymes are degraded and HMF is formed, neither can be reversed by any treatment available to the beekeeper.

Storage management follows the same logic. Honey stored at cool temperatures accumulates HMF slowly; honey stored warm accumulates it much faster. First-in, first-out rotation matters not just for freshness perception but for actual analytical quality. A batch stored over a warm summer at ambient temperature may leave the producer's hands with an HMF level well within the 40 mg/kg limit but arrive at a distant market months later above it, depending on the journey temperature. Exporters, wholesale buyers, and competition honey shows test HMF specifically.

16.8 Color, Flavor, and Terroir

Honey color is commercially important and is graded on a standardized scale. The Pfund grader, or its optical equivalent, measures transmitted light through a honey sample and assigns the result to one of the following categories: Water White, Extra White, White, Extra Light Amber, Light Amber, Amber, and Dark Amber, in order from palest to deepest.

Color correlates loosely with mineral content — darker honeys generally carry more minerals, derived from the plant material they originate in — and with flavor intensity. The correlation is real but imperfect: some dark honeys are intense and complex, others are merely dull; some light honeys are delicate and nuanced, others are thin. Color is not a measure of purity, quality, or freshness. The same floral honey will darken measurably if heated or stored warm, so a dark reading can reflect either a legitimately dark varietal (tulip poplar, buckwheat) or a well-known light honey (sourwood, tupelo) that has been mishandled. The examiner expects a candidate to understand that color is floral-source-diagnostic in fresh honey and thermal-history-diagnostic in honey of uncertain provenance.

From the southeastern US perspective, sourwood honey occupies a position similar to the regional production of fine wine: it commands a premium because of the limited geography of the source trees, the timing of the flow (which follows the main spring flow and falls in a window that requires experience to catch), and the distinctive flavor. Tupelo, drawn chiefly from white (Ogeechee) tupelo in the river swamps of the coastal plain from South Carolina to northwest Florida, is valued partly for its resistance to granulation and partly for its flavor. Both are reliably light on the Pfund scale when properly handled.

Honey flavor is produced by hundreds of volatile compounds — aldehydes, esters, alcohols, acids, and terpenoids — most present at levels measurable only by gas chromatography, but contributing in combination to what experienced tasters perceive. The concept of terroir — the idea that honey from a specific place has a characteristic flavor profile that reflects the flora, the soils, the season, and the beekeeper's management — is not just marketing language; it is chemically real. Monofloral honeys have distinctive chemical signatures that can be used in authenticity assessment. Laboratories can distinguish genuine manuka honey from blended or adulterated products using marker compounds, the same principle applied to other varietals.

16.9 Granulation: Mechanism, Management, and Creamed Honey

All honey can granulate. The question is not whether a given honey will crystallize but when, how fast, and in what crystal form. Understanding the mechanism gives the producer control over the outcome.

16.9.1 The Crystallization Mechanism

Granulation is the crystallization of glucose monohydrate from supersaturated solution. Honey is supersaturated with respect to glucose at room temperature: the concentration of dissolved glucose exceeds what would be in equilibrium with the solid phase. Given a nucleation site and enough time, glucose molecules will organize into crystals, reducing the dissolved concentration until equilibrium is approached. The remaining liquid becomes relatively richer in fructose and water — which is the partial granulation mechanism that elevates liquid-phase moisture described earlier.

Nucleation requires a surface on which crystal formation can begin. Pollen grains, fine wax particles, air bubbles, and pre-formed tiny crystal nuclei all serve this purpose. Very finely filtered honey — though not ultrafiltered — stays liquid longer because it has fewer nucleation sites. Very pure honey without added seed crystals can supercool past the zone of spontaneous crystallization and remain liquid, but this is the exception rather than the rule.

16.9.2 Temperature Dependence

The rate of crystallization is strongly temperature-dependent. Granulation proceeds most rapidly at approximately 57 degrees F, the temperature at which glucose monohydrate crystal growth is fastest. Above 77 degrees F, honey generally remains liquid because the equilibrium shifts: the solubility of glucose increases and the crystal phase dissolves. Honey does not freeze at 32 degrees F, and at refrigerator temperatures (34-40 degrees F) it still granulates, faster than at room temperature. Only at freezer temperatures, around 0 to 10 degrees F, does it become so viscous that crystal growth is effectively arrested. This means that a beekeeper who wants to store liquid honey should do so either warmer than 77 degrees F (avoiding the peak crystallization zone but risking HMF accumulation at higher temperatures) or in a freezer. The worst storage for a honey that must remain liquid is in the basement at 57 degrees F in winter.

16.9.3 Creamed Honey

Creamed honey — also called spun honey, churned honey, or whipped honey depending on the producer — is deliberately controlled granulation that produces a smooth, fine-grained, spreadable product. The process was systematized by Elton Dyce in the 1930s, and the method remains standard: seed a batch of liquid honey with 5 to 10 percent of finely granulated honey, mix thoroughly, pour into containers, and hold at approximately 57 degrees F for one to two weeks. The abundant fine seed crystals cause rapid, uniform crystallization throughout the batch with a crystal grain so fine it is imperceptible on the tongue. The result is a product that is stable at room temperature, will not liquefy and rerun, and appeals strongly to consumers who dislike either sticky liquid honey or coarse crystallized honey.

Creamed honey may be labeled simply as “honey” without qualification because nothing has been added. The seed material is itself honey — the same product in a different physical form. The labeling

identity is identical. This contrasts with the situation for added sweeteners (which do require identification in the label) and reflects the straightforward logic that a physical transformation of a food does not change its identity. Producers can add a descriptor such as “creamed honey” or “whipped honey” voluntarily, and usually do for marketing reasons.

16.9.4 Reversing Granulation

Granulated honey can be reliquefied by gentle warming. A water bath at 95-105 degrees F applied for a period of time sufficient to dissolve the crystals is the standard approach. Temperatures above 107-110 degrees F begin to cause meaningful enzyme degradation and HMF accumulation. Microwave liquefaction is strongly discouraged because it creates hot spots that locally reach temperatures well above any safe threshold, producing uneven heat damage in a batch that may average within range.

16.10 Fermentation: Causes, Prevention, and Detection

Honey ferments when osmophilic yeasts — principally *Zygosaccharomyces rouxii* and related species — reproduce to a population sufficient to drive alcoholic fermentation at a detectable rate. As discussed, these yeasts are present in essentially all honey; the question is whether conditions permit their growth.

The practical prevention of fermentation is multi-layered. The primary control is moisture: harvest only capped or substantially capped honey. The bees’ decision to cap a cell is their judgment that moisture has been reduced to an acceptable level; that judgment is generally reliable, though it is not a substitute for measurement in high-humidity conditions. The widely used standard is to extract only when at least 80 percent of cells are capped, or to measure and extract only at confirmed moisture below 18.6 percent, not merely because the bees have started capping.

Temperature at storage matters independently of moisture. Even honey below 18.6 percent faces elevated yeast activity if held warm: the yeast growth rate at borderline moisture increases substantially between 50 and 80 degrees F. Cool storage — below 70 degrees F, ideally below 60 degrees F — is the second layer of protection.

When honey arrives at the extraction stage with higher moisture than ideal, options for remediation exist. The most reliable is to dry the supers before extraction by holding them in a warm (90-95 degrees F), dry room with fans and a dehumidifier until moisture readings drop to target. This can take 24-72 hours depending on starting moisture and conditions. The honey can also be circulated in a thin film over a warm, dry surface. Blending a high-moisture batch with a low-moisture batch is a mathematically straightforward remedy — calculating a blended moisture from the proportional contribution of each — but requires testing the composite to verify the final result.

Detection of incipient fermentation: foam on the surface of a tank or container is the earliest sign; off odors (sour, yeasty, alcoholic) come next; and a direct moisture reading of the liquid phase of a partially granulated product can reveal that the liquid has climbed above what the composite originally showed. Once fermentation is fully underway, the product cannot be recovered as honey. Mead (honey wine) is the intentional version of this process; spoiled honey is the unintentional result of the same biochemistry without control.

16.11 Extraction and Processing

16.11.1 Timing and Bee Removal

The decision of when to harvest supers requires matching the colony's ripening progress against the beekeeper's production calendar. The 80 percent capping standard is a reasonable operational guide; a refractometer reading below 18.6 percent gives a direct measurement that does not depend on visual assessment. In humid climates, visual capping can be less reliable because bees may cap cells at slightly higher moisture than in dry regions.

Removing bees from supers can be accomplished by several methods, each with a different profile of advantages and disadvantages. A bee escape board — a one-way device placed between the supers and the brood nest — allows bees to move downward through the escape but not return. Over the course of one to two days (typically overnight at minimum, sometimes two nights for large stacks), the super empties naturally. No chemicals are involved, there is no disruption of the colony, and no taint is introduced to the crop. The limitation is time: a bee escape requires advance planning and works best when nights are cool enough to draw the bees down, and cleared supers left unguarded in warm weather invite small hive beetle and robbing. In the humid southeastern US, cleared supers should be removed and extracted promptly.

Fume boards vaporize a chemical repellent (typically butyric anhydride; benzaldehyde and botanical blends have also been sold - use only a product currently labeled for the purpose) beneath a heat-absorbing cover. The vapor drives bees downward rapidly — often in minutes in warm weather. Fume boards are faster than escape boards and practical for operations running many hives in a single visit, but they require attention to temperature (cold weather slows the process; extremely hot weather can push concentrations to levels that taint the honey), and they must be used per label. The chemical scent generally dissipates during extraction and processing if concentrations are kept within normal use patterns.

Bee blowers force air through the combs to dislodge bees. They are effective, chemical-free, and fast, but they are disruptive to the colony and neighboring hives. The noise and disturbance can trigger defensive behavior and robbing behavior in a dearth, which matters in a densely managed apiary.

Shaking frames individually works at small scale and introduces no chemicals, but requires the beekeeper to carry each frame away from the colony immediately and prevents using the method at the scale of a commercial operation.

16.11.2 Extractors: Tangential vs. Radial

Honey extractors spin the frames and use centrifugal force to fling the honey off the comb. Tangential extractors hold the frames so the face of the comb is parallel to the drum wall; centrifugal force extracts one face at a time, and the operator must flip each frame to extract the other side. Tangential design is the standard for baskets holding a small number of frames, typically two to four at a time, and is common among small-scale producers.

Radial extractors hold the frames like spokes of a wheel, with the top bar facing outward. In this orientation, centrifugal force acts on both faces of the comb simultaneously, extracting both sides at

once without operator intervention between passes. Radial extractors run more productively for larger volumes and with less handling of the frames, which reduces comb breakage. They are the standard design for commercial operations. The tradeoff is cost and the minimum batch size: radial extractors designed for eight or more frames are less efficient when run with just two or three frames, and the initial investment is higher.

16.11.3 Uncapping

Before extraction, the wax cappings must be removed from each cell face. Methods include: a heated electric or steam knife, which melts through the cappings; a cold serrated knife; a roller or spiked drum that pierces rather than removes cappings; and an uncapping plane or fork, useful for combs that are not fully capped. The cappings themselves carry honey and can be drained and processed separately. Cappings wax is the highest-quality wax in the hive, being new white wax with minimal propolis contamination, and commands a premium.

16.11.4 Settling, Filtering, and Ultrafiltration

After extraction, honey contains wax particles, air bubbles, foam, and fine debris. Standard practice is to allow the honey to settle in a heated tank, typically at 95-100 degrees F, for 24-48 hours. Wax and foam rise to the surface and are skimmed; the clear honey is drawn from below. Straining through cloth or fine mesh screens removes larger particles without disturbing pollen content.

Pollen in honey is the primary means of establishing floral source and geographic origin. A pollen analyst (melissopalynologist) can examine the pollen spectrum of a honey sample and, in most cases, identify the dominant floral sources and the geographic region where they grow. This is the technical basis for authentic varietal claims and for tracing the origin of imported honey.

Ultrafiltration, applied under pressure through fine membranes, removes pollen from honey entirely. This is not filtration in the ordinary sense — it is a fundamentally different process, one that strips the honey of its botanical and geographic traceability. Ultrafiltration defeats the primary method of origin determination and is one mechanism by which honey has been laundered through third countries to evade duties and origin labeling requirements. The FDA's 2018 honey labeling guidance does not address filtration; the USDA grade standards distinguish "strained" from "filtered" honey. Ordinary straining and settling that retain pollen are normal practice and do not compromise traceability. Ultrafiltration that removes pollen is categorically different and raises specific regulatory concerns about misbranding and origin fraud.

16.12 Wet Supers: Management After Extraction

Wet supers — supers of extracted comb still carrying a film of residual honey — represent a significant management decision in the immediate aftermath of extraction. The residual honey must be recovered, and the comb must be prepared for storage or reuse without creating problems in the apiary.

The standard method is to return wet supers to the colonies that produced them, placed above an inner cover on strong colonies, typically in the late afternoon to minimize the risk of triggering robbing. The

colonies clean the residual honey quickly and efficiently over a day or two. Once the comb is dry, the supers are removed, inspected, and stored.

Open placement of wet supers in the apiary — setting them out in the open for the bees to work — is strongly discouraged for two reasons specific to the humid Gulf and Atlantic coastal plain environment. First, during the summer and early fall dearth, the prospect of free honey creates conditions for apiary-wide robbing that can devastate colonies, particularly those that are smaller or queenless. Second, open placement mixes bees from many colonies over shared comb, providing a highway for disease transmission. A diseased colony contributing bees to an open wet super sends contaminated debris into every colony in the apiary. The risk of transmitting American foulbrood spores, in particular, through shared comb is well documented.

Wet supers that are stored before the colonies can clean them must be managed carefully. The residual honey and pollen sustain both small hive beetle larvae and wax moth larvae; supers stored even briefly in warm conditions with residual moisture can emerge from storage with significant wax and comb damage. The appropriate response is to store wet supers in a pest-tight space only after they have been dried by the colonies or by mechanical means, or to freeze them before storage.

16.13 Comb Honey Production

Comb honey — honey in the wax comb, sold as a section, cut comb, or round section — places different demands on both the beekeeper and the product than extracted honey does.

The wax is part of the product, which means the wax must be safe to consume and visually attractive. Old brood comb is disqualified on both counts: it is dark, it carries residues of brood, propolis, and any miticides that were applied in the hive, and it cannot be whitened by any practical method. The only acceptable wax for comb honey is new wax drawn from clean, residue-free foundation during the season of production. The wax residue status of foundation is therefore not an abstract regulatory concern but a direct product-quality requirement: foundation carrying miticide residues impregnated from hive use cannot be used for comb honey.

Because appearance is central to the value of the product, management must prevent travel staining — the browning of wax cappings caused by bee traffic over the cells. Sections should be removed from the colony as soon as they are fully capped, before prolonged bee traffic discolors them. Incompletely capped sections reduce in grade significantly. Structural failures (collapsed or broken comb) make the product unmarketable in section form.

The management to produce comb honey concentrates bees into restricted space during a reliable heavy flow, using small sections (traditional wood sections, Ross rounds, or Hogg halfcombs) that bees will fill completely before moving on. This requires strong colonies, a predictable main flow, and a beekeeper willing to remove supers at peak rather than letting them sit through a dearth. In the southeastern US, the main spring flow of tulip poplar, blackberry, and clover is the primary window; sourwood, where available, provides a subsequent opportunity.

16.14 Adulteration and Fraud Detection

Honey adulteration — adding cheaper sugars to bulk up the product or reduce cost — is an ongoing enforcement challenge, and the analytical methods used to detect it are examined at the master level.

16.14.1 C4 Adulteration and Stable Carbon Isotope Analysis

Sugarcane and corn are C4 photosynthesis plants — they fix atmospheric carbon through a pathway that discriminates less against the heavier carbon isotope (carbon-13) than the C3 pathway used by most nectar plants. As a result, C4 plant material is isotopically heavier (higher ratio of carbon-13 to carbon-12, expressed as a less negative delta-13C value) than C3 plant material. Honey proteins are normally derived from the nectar and pollen of the same plants the bees are visiting, so they are usually isotopically light in the same way the honey's sugars are. If corn syrup or cane syrup is added, it brings isotopically heavy carbon with it, shifting the delta-13C of the sugars while the protein remains unchanged.

The analytical elegance is in using the honey's own protein as an internal standard. By comparing the isotopic signature of the honey's sugars against the isotopic signature of its own protein, the AOAC method can detect C4 sugar addition at roughly 7 percent or more without needing an external reference standard of the same floral honey. The protein provides that reference, allowing the method to control for the natural isotopic variation that exists among genuine honeys from different plants.

The method's limitation is equally important for the exam: it does not detect adulteration with sugars from C3 plants, such as beet sugar or rice syrup. Beet sugar and rice syrup are isotopically indistinguishable from most honey sugars by the stable carbon isotope method. Detecting C3 adulteration requires other approaches: nuclear magnetic resonance (NMR) profiling, which detects marker compounds that are present in honey but absent in refined syrups; stable hydrogen and oxygen isotope ratios, which reflect the water source; and oligosaccharide profiling, which detects compounds produced by enzymatic modification of syrup starches that are not present in genuine honey. Detection and adulteration are in an arms race: official methods lag behind the newest tailor-made syrups, and C3 adulteration remains more analytically challenging than C4 adulteration, which is why NMR profiling, LC-IRMS and traceability and document checks are used alongside the isotope test.

16.14.2 Ultrafiltration and Honey Laundering

As noted in the extraction section, ultrafiltration removes pollen. This makes geographic origin determination essentially impossible because the pollen record is destroyed. The practical significance is that ultrafiltrated honey cannot be verified as originating from the country stated on the label. This has been used in documented cases to launder honey through third countries with lower import tariffs or fewer regulatory concerns, transshipping it to avoid duties or to obscure country of origin. Enforcement against honey laundering has come chiefly through Customs and Border Protection and federal prosecutors, under customs, antidumping-duty and country-of-origin rules; the FDA's 2018 labeling guidance does not address ultrafiltration.

16.15 Grading, Labeling, and Legal Obligations

16.15.1 Voluntary Grade Standards

The United States Standards for Grades of Extracted Honey, administered by USDA AMS, are voluntary. A producer is not required to have honey graded, and the grade designation need not appear on a label unless the producer has requested USDA grading and wishes to display it. The grade standards define four grades — Grade A, Grade B, Grade C, and Substandard — based on moisture content, flavor and aroma, absence of defects, and clarity. Grade A requires moisture at or below 18.6 percent (a limit that tracks, but sits slightly above, the level at which fermentation is reliably prevented), freedom from fermentation, good flavor and aroma without off-flavors, and essentially clean appearance. Grade B keeps the 18.6 percent moisture limit and relaxes the other factors; Grade C allows moisture up to 20 percent; Substandard fails to meet Grade C.

The voluntary nature of grading is a distinction the examiner reliably tests. Producing honey under mandatory food safety law (the FD&C Act's adulteration provisions and, for operations that must register as food facilities, FDA's Preventive Controls for Human Food rule, 21 CFR 117) and labeling it accurately (under the FD&C Act's misbranding provisions) are not voluntary. Grading is. A producer who prints "USDA Grade A" on a label is making a representation that is subject to verification; a producer who makes no grade claim is subject only to the requirement that the product is what its label says it is and is produced safely.

16.15.2 Mandatory Labeling: What Must Be on the Label

Under federal law, a honey label must carry:

- A **statement of identity**: "Honey" for pure honey. Nothing more elaborate is required; "Pure Honey" is acceptable but the word "pure" is an implied representation that the product contains no added ingredients.
- **Net quantity**: stated by weight, in both US customary and metric units, in the required type size and placement.
- **Name and place of business** of the packer or distributor: an address sufficient to find the business, not a website alone.
- **Country of origin** for imported honey: required under customs law (the Tariff Act) and its regulations.
- **Nutrition labeling**: required unless an exemption applies, most commonly the retail direct-sale exemption (21 CFR 101.9(j)(1)) or the low-volume small-business exemption (21 CFR 101.9(j)(18)). The FDA's exemption thresholds change from time to time; producers should verify current exemption criteria.

State requirements layer on top of these federal minimums. Some states require the infant botulism warning statement; some require the producer's license number; weights-and-measures offices enforce net weight requirements independently of FDA. The cottage-food status of honey varies by state; some states exempt honey from cottage-food licensing as a raw agricultural commodity, but state labeling

requirements still apply and may differ from federal standards. Cottage food exemptions from commercial kitchen requirements do not exempt the producer from labeling requirements.

16.15.3 Pure Honey vs. Honey Products

The FDA's 2018 guidance on honey labeling is clear: honey to which any sweetener has been added is not honey. It must be given a name that accurately describes what it is — "blend of honey and corn syrup," for example — and an ingredient statement listing all ingredients in descending order of predominance by weight. This applies regardless of the nature of the added sweetener: corn syrup, rice syrup, beet sugar, or any other ingredient makes the product something other than honey. The misbranding provision of the FD&C Act (21 U.S.C. 343) is the statutory basis, and it applies to small producers selling retail just as it does to commercial packers.

The same logic applies to the case of a beekeeper who feeds sugar syrup to colonies with honey supers in place. If the bees store syrup in the honey supers, that syrup is in the product, and selling it as honey is misbranding. The labeling consequence is not merely a technical violation; it is a statement that the product is something it is not, which is the core definition of misbranding under federal law.

16.15.4 Floral Source Claims

A label may identify a floral source — "clover honey," "sourwood honey," "wildflower honey" — if there is information supporting that the named plant is the chief floral source. For varietals from plants with limited geographic range or short bloom windows, pollen analysis provides documentation. "Wildflower honey" requires that the honey actually comes from a diverse wildflower flora, not that it comes from a managed crop. The claim need not be accompanied by pollen analysis documentation on the label, but the producer should have the basis for the claim and be prepared to defend it if challenged.

16.15.5 Disease Claims and the Drug Problem

Making a claim on a honey label or in associated marketing materials that the product treats or prevents a disease or medical condition converts the product into an unapproved drug under federal law (21 U.S.C. 321(g)). A drug must go through FDA's approval process before sale; selling an unapproved drug is a criminal violation. FDA has issued warning letters to honey producers and hive product sellers for disease claims including claims about wound healing, antifungal properties, and immune support. Implied claims — a picture of a person with a sore throat alongside the honey, or a testimonial quoted on the label — are treated as disease claims as much as explicit statements are.

The appropriate commercial communication is to describe what the honey is — its floral source, its origin, its flavor profile, its production method — and to allow quality to speak for itself. "Raw honey from mountain wildflowers" tells the buyer something accurate and useful. "Raw honey from mountain wildflowers that boosts immune function" is a disease claim that triggers regulatory scrutiny.

16.16 Food Safety Planning and Honey House Management

The FDA Food Safety Modernization Act and its implementing rules, including the Preventive Controls for Human Food rule (21 CFR 117), require food facilities that must register with FDA to implement food safety plans. For honey, that means operations such as packers who buy or blend honey from others or

process beyond farm activities; a beekeeper who only extracts and bottles his or her own honey is generally treated as a farm. The FD&C Act adulteration and misbranding provisions apply to all honey sold, and the state department of agriculture sets inspection and licensing rules. Small producers may qualify for exemption or for modified requirements, but the obligation to produce food safely under adequate sanitary conditions applies regardless of exemption status.

16.16.1 Hazard Categories

A food safety plan for a honey operation should address three hazard categories:

Physical hazards include glass fragments from broken jar handling, metal fragments from equipment, insects, rodents, and foreign material from the environment. Good manufacturing practice — keeping the honey house clean, screening windows and doors, inspecting equipment for wear, and not using glass-lined containers near the extraction line — controls most of these.

Chemical hazards include cleaning and sanitizing agents left as residues on equipment, lubricants from extractor bearings and uncapping equipment, and pesticide residues carried in from the hive. Pesticide residues are the most significant chemical concern specific to beekeeping: amitraz and coumaphos have established maximum residue limits in international markets (oxalic acid, a natural honey constituent, is exempt), and a honey operation that treats colonies without record-keeping cannot trace which batches of honey came from treated hives during or after treatment.

Microbiological and quality hazards are principally moisture — the fermentation risk — and the quality degradation associated with heat and time. The control is moisture measurement, temperature monitoring, and documented lot-specific testing.

16.16.2 Lot Coding

Lot coding is not legally required in all contexts, but it is the mechanism that allows a proportionate response to a quality problem. If a single batch of honey develops fermentation, a clearly coded lot can be identified, the customers who received it can be notified, and the remaining inventory of that lot can be held. Without lot coding, a problem discovered in one jar puts the entire season's production in question, because there is no basis for distinguishing which jars share the same history as the problematic one. In practice, a lot code needs to identify at minimum the extraction date or batch number and, for large operations, the specific tank. Date codes alone serve this function adequately for most small producers.

In the humid southeastern Gulf and Atlantic coastal region, a honey house food safety plan should also specifically address small hive beetle exclusion from the facility. Infested cappings or raw comb brought into the honey house can establish a beetle population in the facility itself, contaminating equipment and producing unsalable product. Tight screening, elimination of organic waste, and prompt disposal of cappings and debris are part of the physical controls.

16.17 Storage: Sealed, Cool, and Stable

Honey is hygroscopic at any moisture content within the normal range — it absorbs water vapor from the surrounding air when exposed to humid conditions. This is not a property that appears only above

some threshold; a 17 percent honey in an open container in a humid environment will gain moisture from the air. In the humid southeastern US, where summer relative humidity can be at or near saturation during daylight hours, open storage of honey is a reliable path to fermentation. Sealed containers are not optional for stored honey; they are the primary moisture control.

The optimal storage conditions are cool and dark, but the recommendation against refrigeration is specific: refrigerator temperatures (34-40 degrees F) promote granulation compared with room temperature, although the fastest rate is at about 50-59 degrees F. Cold below about 50 degrees F slows or stops yeast growth, but refrigeration accelerates granulation, and the water released into the liquid phase can trigger fermentation as soon as the honey warms, so it is a poor long-term fix for honey above the fermentation threshold. Freezing — at 0 to 10 degrees F — genuinely arrests both granulation and enzyme degradation with minimal HMF accumulation, and is a legitimate long-term storage method for honey that will not be needed for months or years.

The deteriorative processes of primary concern in storage — HMF accumulation, enzyme degradation, color darkening, and flavor dulling — are all accelerated by heat and are irreversible. Granulation is also accelerated by the wrong temperature but is reversible by gentle warming. Knowing which changes can be undone and which cannot informs the priority given to temperature management in the honey house and warehouse.

16.18 Numbers to Know Cold

Figure	Value	Why it is that value
Fructose content of honey	~38%	Principal simple sugar from nectar; present in excess of glucose in most honeys; fructose does not crystallize
Glucose content of honey	~31%	Second principal sugar; glucose monohydrate is the crystal form in granulated honey; drives granulation
Water content (properly ripened)	17-20%	Bees reduce nectar moisture by evaporation; at or below 18.6% meets Grade A; below about 17% is safe from fermentation
Fermentation threshold	~17-17.5% (risk rises steeply above ~18-19%)	Below about 17%, water activity is too low for osmophilic yeasts to reproduce at harmful rates whatever the yeast count
USDA Grade A moisture maximum	18.6%	Commercial/regulatory boundary for acceptable trade honey; tracks the fermentation threshold more closely than the 20% limits do; Grade C allows up to 20%
Codex moisture maximum	20% (general)	International standard; a looser general limit than USDA Grade A (18.6%); some exception products differ
pH of honey	3.2-4.5	Gluconic acid (from GOX action on glucose) is dominant organic acid; contributes to antimicrobial activity

Figure	Value	Why it is that value
Honey water activity (Aw)	~0.5-0.6	Sufficiently low to inhibit most microorganisms; osmophilic yeasts tolerate it at higher moisture
HMF limit (Codex, most honey)	<40 mg/kg	Fresh honey has essentially 0; forms from fructose dehydration under acid and heat; limit set to exclude heat-abused or aged product
HMF limit (Codex, tropical honey)	<80 mg/kg	Ambient temperatures in tropical origins cause some accumulation before export; higher limit accommodates this
Diastase number (Codex minimum)	8 (Schade scale); 3 for naturally low-enzyme honeys	Minimum acceptable enzyme activity; naturally low-diastase honeys (some citrus) have a lower minimum, read together with HMF
Temperature of fastest granulation	~57 degrees F	Glucose monohydrate crystal growth rate peaks here; storage near this temperature accelerates crystallization
Temperature above which liquid honey is stable	>77 degrees F	Glucose solubility rises enough to keep crystals from nucleating; prolonged storage at this range risks HMF
Creamed honey seed proportion	5-10% by weight	Enough seed crystals to saturate the batch with nucleation sites; less seed risks incomplete or uneven crystallization
Creamed honey holding temperature	~57 degrees F	The temperature at which crystallization proceeds fastest; matches the seed crystal growth optimum
Honey house maximum heating temperature	100-110 degrees F	Above this, enzyme degradation and HMF accumulation accelerate; 107 degrees F is a commonly cited upper operational limit
Infant feeding restriction	Under 12 months	*C. botulinum* spores in honey can germinate in the immature infant gut; older children and adults are at negligible risk
Pfund scale range	Water White to Dark Amber	Seven categories from palest to darkest; measured by light transmission; correlates with mineral content
Sucrose content (normal maximum)	~5% (Codex)	Bee invertase converts sucrose to fructose and glucose during ripening; elevated sucrose suggests immaturity or adulteration
GOX activity in undiluted honey	Essentially zero	GOX is inhibited by the high sugar concentration; only activates and produces H2O2 when honey is diluted
Carbon isotope ratio analysis sensitivity	C4 sugars only	Detects cane or corn syrup (C4 plants) via delta-13C difference; cannot distinguish C3 plant syrups (beet, rice) from honey

16.19 Common Misconceptions

Misconception: Granulated honey has gone bad and should be discarded. **Correction:** Granulation is a natural physical transformation, not spoilage. All honey can granulate, and granulation indicates high glucose content and cool storage — both neutral-to-positive attributes. Granulated honey is safe to eat and can be reliquefied by gentle warming below 110 degrees F. Fermentation is the spoilage process to watch for, and it is detectable by smell and the presence of foam.

Misconception: If honey passes the Grade A moisture standard, it will not ferment. **Correction:** The grade standard and the fermentation threshold are different concepts. Grade A's maximum is 18.6 percent, but fermentation is reliably prevented only below about 17 to 17.5 percent; between there and 18.6 percent, honey with a high yeast count can still ferment, especially if stored warm or if it begins to granulate and the liquid phase gains water. Honey that passes only the more permissive Grade C standard (up to 20 percent) is at greater risk still: a batch at 19.5 percent fails Grade A, passes Grade C, and is a real fermentation risk.

Misconception: Pasteurizing honey makes it safe from Clostridium botulinum for all consumers. **Correction:** Destroying *C. botulinum* spores requires temperatures that completely ruin honey — beyond any practical heat treatment used in processing. The infant feeding advisory exists precisely because no practical processing can be relied on to render honey spore-free. Pasteurization as practiced commercially (temperatures around 140-165 degrees F briefly) destroys yeasts and delays granulation but does not kill endospores. The advisory applies to all honey, including commercially processed product.

Misconception: Honey is a sterile product with no living organisms. **Correction:** Honey is microbially stable under normal conditions, not sterile. Osmophilic yeasts are present in all honey and will cause fermentation if moisture rises sufficiently. *C. botulinum* spores are present in some honey. The antimicrobial properties of honey suppress most organisms under the conditions found in properly harvested honey, but honey is not sterile in the way that a heat-processed canned product is.

Misconception: The hydrogen peroxide in honey accounts for its antimicrobial activity in everyday storage. **Correction:** Glucose oxidase, which produces H2O2, is inhibited in undiluted honey by the very high sugar concentration. H2O2 is not being generated continuously in a jar of honey on the shelf. The primary antimicrobial factors in stored honey are low water activity and low pH. The peroxide system activates when honey is diluted, which is why it is relevant to wound-care and therapeutic applications but not to the keeping quality of sealed product.

Misconception: Straining honey through a fine filter removes pollen and is the same thing as ultrafiltration. **Correction:** Ordinary straining and settling remove wax particles, air bubbles, and debris while retaining pollen grains, which are large enough to settle or float depending on density. Ultrafiltration applies pressure to force honey through membranes with pore sizes that exclude pollen. The two processes have different outcomes: strained honey retains its pollen record for botanical and geographic traceability; ultrafiltered honey does not. The regulatory significance of the distinction is substantial in the context of origin labeling and fraud detection.

Misconception: USDA Grade A honey is legally required to meet all grade criteria and is regulated in the same way as mandatory food safety standards. **Correction:** USDA grade standards for extracted honey are voluntary. A producer may request grading and display the designation, but no regulation requires honey to be graded before sale. Mandatory requirements come from FDA food safety law and the FD&C Act's misbranding provisions; grade standards provide a common commercial vocabulary and are useful in wholesale trade and competition showing but have no mandatory enforcement mechanism in routine retail.

Misconception: A disease claim on a honey label is permissible if the product truly has the described property. **Correction:** Whether the claim is accurate is irrelevant to its regulatory status. Under federal law, a claim that a product treats or prevents a disease or medical condition makes the product a drug, which must go through FDA approval before sale. No honey has received that approval, so any disease claim renders the product an unapproved drug and the label misbranded. FDA has pursued enforcement actions against honey sellers for exactly such claims, including implied claims through imagery and testimonials.

Misconception: Refrigerating honey prevents fermentation and is good long-term storage practice. **Correction:** Refrigerator temperatures (34-40 degrees F) fall within the range of active granulation, so refrigerating liquid honey accelerates crystallization. Cold slows yeast growth, but the water released into the liquid phase can trigger fermentation as soon as the honey warms. Honey below about 17 percent moisture will not ferment regardless of storage temperature, and honey within the Grade A limit (18.6 percent) rarely does if kept cool and sealed; honey above the threshold is better managed by drying before storage, not by refrigeration. Freezing (0-10 degrees F) is effective for long-term storage and does not carry the crystallization acceleration problem that refrigerator temperatures do.

Misconception: Adding a small amount of any natural ingredient to honey — such as herbs, royal jelly, or pollen — still produces a product that can be labeled simply "honey." **Correction:** Adding anything to honey produces a product that is not honey and must be labeled with an accurate description and a complete ingredient statement. The FDA's guidance is unambiguous on this: honey is the product produced by bees from nectar; adding an ingredient makes it something else. This applies regardless of the naturalness or perceived value of the additive.

Misconception: The darker the honey, the more nutritious it is. **Correction:** Darker honey generally has higher mineral content, which can be measured analytically, but this does not translate to a clinically meaningful nutritional advantage. Color is a floral-source indicator and a heat-history indicator in fresh honey; at master level, the correct association is color-to-origin and color-to-handling-history, not color-to-nutritional-value. Making nutritional superiority claims for dark honey without substantiating evidence would itself raise labeling concerns.

Misconception: The isotope ratio method can detect any type of honey adulteration. **Correction:** The stable carbon isotope ratio (AOAC) method is effective for detecting adulteration with C4 sugars — cane sugar and corn syrup — at roughly 7 percent or more, though it is unreliable for low-protein or ultrafiltered honeys. It is essentially ineffective against adulteration with C3 sugars such as beet sugar

and rice syrup, which are isotopically similar to the C3 nectar plants that produce most honey. Detecting C3 adulteration requires NMR profiling, oligosaccharide analysis, or other complementary methods.

16.20 Self-Check Questions

- Explain why a honey with a high fructose-to-glucose ratio (and a low glucose-to-water ratio) granulates slowly, while one with a fructose-to-glucose ratio near or below about 1.1 (and a glucose-to-water ratio above about 2) granulates rapidly. Identify one common floral source associated with each extreme.

- A producer extracts a batch at 19.2 percent moisture, which fails the USDA Grade A maximum (18.6 percent) but passes the more permissive Grade C maximum (20 percent). Describe the fermentation risk the producer faces, identify the mechanism that could make the problem worse during storage, and state two acceptable options for managing it.

- Distinguish the mechanism by which hydrogen peroxide contributes to honey's antimicrobial activity in wound care from the role it plays in sealed, undiluted honey on a shelf. Why is the difference practically important?

- A refractometer read at 80 degrees F shows 18.0 percent moisture for a honey sample that is in fact at 17.2 percent moisture. Explain the physics of this error and describe the correct procedure for obtaining an accurate reading.

- A customer claims that a producer's honey crystallized in the jar and that this constitutes evidence the honey was adulterated with corn sugar. Write a factually accurate explanation for the customer that addresses both the mechanism of granulation and the actual method for detecting corn sugar adulteration.

- Explain what hydroxymethylfurfural is, identify two conditions that cause it to accumulate in honey, and describe how a paired HMF/diastase assessment is more diagnostically useful than either measurement alone.

- A producer labels a product "Honey with Elderberry Syrup — Boosts Immune Function and Fights Colds." Identify every regulatory problem this label creates, citing the relevant legal framework for each.

- Describe the Dyce creamed honey process in mechanical terms, explain why it produces a finer-grained product than natural granulation, and state why the resulting product may legally be sold as "honey" without qualification.

- Explain why ordinary straining of honey and ultrafiltration of honey represent categorically different processes from the perspective of origin traceability, and describe the regulatory context in which this difference matters.

- Identify the three layers of hazard a honey house food safety plan should address, give one concrete example of each, and explain why lot coding matters as a management tool independent of those hazard categories.

- A producer runs colonies in the Gulf coastal plain through a summer dearth and, after the fall extraction, sets wet supers out in front of the hives for the bees to clean. Describe the two principal problems this creates and the preferred alternative method.
- Compare tangential and radial extractors across three axes: how they extract, the labor requirement per frame, and the scale at which each is most practical.
- Explain the internal protein standard in the stable carbon isotope ratio test for honey adulteration: what it controls for, why it is necessary, and what class of adulterants it cannot detect.
- State what must legally appear on a retail honey label under federal requirements, and identify two categories of information that small producers commonly omit.

16.21 Self-Check Answers

- Fructose does not crystallize under normal honey storage conditions; glucose monohydrate does. When glucose is high relative to water and fructose, the solution is supersaturated with the crystallizing component, nucleation occurs readily, and crystal growth proceeds quickly. When fructose is high relative to glucose (above about 1.3), the glucose that is present is diluted below the threshold at which rapid crystallization occurs. Canola honey is the standard example of a high-glucose honey that can granulate in the comb; tupelo honey is the textbook high-fructose example, valued specifically because it remains liquid even after extended storage.
- The batch has cleared the Grade C standard by less than one percent but sits above the Grade A maximum it failed (18.6 percent) and well above the 17 to 17.5 percent level below which fermentation is reliably prevented. Osmophilic yeasts present in the honey can reproduce at this moisture, particularly if the honey is held at warm temperatures. The mechanism that worsens the problem is partial granulation: as glucose crystallizes out of solution, the liquid phase becomes relatively enriched in water, potentially raising it from 19.2 percent to roughly 21 to 22 percent in the unfrozen fraction. Acceptable options are: dry the honey by exposing it to warm (90-95 degrees F), low-humidity air with fans until moisture drops below 18.6 percent, then test and bottle; or blend with a confirmed dry batch, calculate the expected blended moisture, verify by refractometer, and bottle the composite. Bottling as-is is not acceptable. Adding any substance to lower moisture would make the product not honey.
- In a wound or diluted-honey application, honey's high sugar concentration is disrupted by dilution from wound exudate or intentional dilution in a preparation. Glucose oxidase (GOX) becomes active at the lower sugar concentration and continuously oxidizes glucose to gluconic acid and hydrogen peroxide. That H_2O_2 is the active antimicrobial compound. In a sealed jar of undiluted honey, the sugar concentration is so high that GOX is inhibited; no H_2O_2 is being generated. The shelf stability of honey comes from low water activity and low pH, not from peroxide. This matters practically because a beekeeper who claims sealed honey is antimicrobial because of peroxide is making an inaccurate statement about a mechanism that is not active in the product as stored.
- The refractive index of a sugar solution decreases as temperature increases — a warm sample bends light less sharply, producing a reading that corresponds to lower sugar concentration and thus higher apparent moisture. A sample at 80 degrees F in an instrument calibrated at 68 degrees F will overstate moisture relative to the actual 68-degree-F value. The physics are those

of a temperature-dependent optical property. The correct procedure is to allow both the honey sample and the refractometer to equilibrate to a common temperature within the instrument's operating range (typically 59-77 degrees F), read the temperature, apply any correction factor specified for that temperature, and if still uncertain, bring both to 68 degrees F specifically, using a thermometer to confirm.

- Crystallization in honey is the normal, predictable behavior of glucose monohydrate coming out of supersaturated solution. It is not evidence of added sugar and does not indicate adulteration. All honey can granulate; honeys with high glucose content granulate more rapidly and form coarser crystals if granulation is uncontrolled. Detecting adulteration with corn sugar requires stable carbon isotope ratio analysis (AOAC method 998.12), which compares the delta-13C value of the honey's sugars against its own protein. Corn is a C4 plant; its sugars are isotopically distinct from the C3 plant sources of most nectar. This is a laboratory test, not detectable by appearance, texture, or granulation behavior.

- Hydroxymethylfurfural (HMF) is formed when fructose undergoes acid-catalyzed dehydration, losing three water molecules to form a ring compound. It is essentially absent from fresh honey and accumulates under two conditions: heat — even brief warming to high temperatures greatly accelerates formation — and warm storage over time. Adulteration with certain invert syrups also introduces pre-formed HMF. A paired assessment with diastase is more diagnostic because diastase activity also declines with heat and age, and both indicators pointing the same direction (high HMF, low diastase) provides stronger evidence of heat damage or age. However, some floral honeys are naturally low in diastase when fresh; in those cases, low diastase alone is not diagnostic. When diastase is naturally low but HMF is also low, the honey is likely fresh and fine; when diastase is low and HMF is elevated, the honey has been heated or is old.

- The label creates at least three distinct regulatory problems. First, the product is not honey: anything added to honey makes it something else, and the label must identify it accurately with an ingredient statement (FD&C Act, 21 U.S.C. 343, and FDA's 2018 honey labeling guidance). Second, the elderberry claim may be a structure/function or disease claim depending on its context, but "Fights Colds" is almost certainly a disease claim (prevention of a condition), which converts the product to an unapproved drug (21 U.S.C. 321(g)) and renders the label misbranded. Third, "Boosts Immune Function" is at best a structure/function claim: for a conventional food such a claim must be truthful and rest on the food's nutritive value (FDA notification and a disclaimer are dietary-supplement requirements), and an immunity claim on a product sold against colds is likely to be read as a disease claim. The producer should relabel the product accurately as a blend, remove the therapeutic claims, and consult with a regulatory advisor if structure/function language is desired.

- In the Dyce process, liquid honey is seeded with 5-10 percent finely ground, fully granulated honey and mixed without incorporating air. The seed provides an abundance of pre-formed crystal nuclei distributed uniformly throughout the batch. The honey is then poured into its final containers and held at approximately 57 degrees F — the temperature at which glucose monohydrate crystal growth is fastest. With nuclei uniformly distributed and growth conditions optimal, crystallization is rapid and simultaneous throughout the mass, producing crystals so fine that individual crystals are imperceptible to the tongue. Natural uncontrolled granulation, by contrast, begins from fewer nucleation sites and proceeds unevenly, producing larger, coarser crystals. The product may be labeled "honey" because the seed crystal is itself honey, nothing has been added or removed, and the transformation is purely physical.

- Ordinary straining forces honey through cloth or screen to remove wax, foam, and debris large enough to be caught; pollen grains (5-200 microns) pass through and remain in the honey. A melissopalynologist examining that honey can identify the pollen spectrum — which plants it came from and, given the geographic distribution of those plants, where in the world it was produced. Ultrafiltration applies pressure across membranes with pore sizes small enough to exclude pollen, which is removed from the honey entirely. The pollen record is destroyed. This matters in the context of origin fraud: honey laundered through a third country to evade tariffs or misrepresent origin can only be traced by its pollen content; ultrafiltered honey has no such traceable content. The FDA's 2018 labeling guidance does not address the practice; the concern arises in customs and country-of-origin enforcement, where transshipped honey has been a recurring target, and in the USDA grade standards, which distinguish strained from filtered honey.

- Physical hazards: glass from broken jars, controlled by avoiding glass containers near the extraction line and by inspection protocols. Chemical hazards: antibiotic or miticide residues, controlled by treatment records, withdrawal periods, and not extracting from colonies within the label-required interval after treatment. Microbiological hazards: fermentation from high moisture, controlled by extraction standards and moisture testing. Lot coding matters independently of all of these because it provides the operational mechanism for a limited response to a discovered problem. Without lot coding, discovering fermentation in one jar forces a choice between recalling all product or recalling nothing; with coding, only the lot containing the problem needs to be acted on.

- Open placement triggers apiary-wide robbing during the late-season dearth. Colonies across the apiary, including weaker and smaller ones, detect the freely available honey and mount robbing activity that can overwhelm and kill target colonies. Disease transmission is the second major problem: bees from all colonies comingle over shared comb, and any disease organisms — *Paenibacillus larvae* spores in particular — present in the combs or in bees from a single diseased colony are distributed to all colonies visiting the shared comb. The preferred alternative is to return wet supers to the hive they came from, placed above an inner cover, in the late afternoon, so bees clean the supers within one to two days and the residual honey is recovered without exposing it to the entire apiary.

- In a tangential extractor, the frame face is parallel to the drum wall; centrifugal force acts on the exposed face, pushing honey out through that side while the opposite face is not efficiently extracted. The operator must reverse each frame midway through the cycle to extract both sides — a two-pass process. Labor per frame is higher because of the manual flip for every frame, and the need to avoid overloading the first side before reversing requires attentive operation. Tangential extractors holding two to four frames are practical and economical for small-scale producers. In a radial extractor, frames are mounted like spokes with the top bar outward; centrifugal force acts simultaneously on both faces. The operator loads the frames and runs the extractor without flipping, reducing handling labor substantially. Radial extractors are the standard for operations running dozens of hives and tens of supers; they are less economical at the two-to-four-frame scale because of cost and the inefficiency of running a large basket partially loaded.

- The internal standard controls for the natural isotopic variation among genuine honeys. Different C3 plants fractionate carbon isotopes slightly differently, so a legitimate honey from a clover-dominated source will have a slightly different delta-13C from one derived primarily from

buckwheat or citrus. If the method simply measured absolute delta-13C of the honey's sugars against a generic reference value, some genuine honeys would test as adulterated and some adulterated samples from isotopically heavier floral sources might escape detection. By instead measuring the honey's sugar fraction against its own protein fraction — which originates in the same floral environment — the method controls for this variation. Protein and sugar from the same genuine honey track each other isotopically; when C4 sugar is added, the sugar fraction shifts toward heavier values while the protein, derived from the original honey, does not. The method cannot detect C3 adulterants (beet sugar, rice syrup) because those adulterants are isotopically indistinguishable from C3 floral nectar.

- Federal requirements: (1) statement of identity ("honey" for pure honey); (2) net quantity of contents, stated by weight in both metric and US units in required type size and placement; (3) name and place of business of the packer or distributor — a street address, not a website; (4) country of origin for imported honey; and (5) nutrition facts labeling unless the producer qualifies for a small business exemption. Two commonly omitted elements: net weight is frequently understated or formatted incorrectly (type size and placement have specific requirements under 21 CFR 101.105); the business address is often omitted by producers who list only a business name or a website. State requirements — license numbers, infant botulism warnings, weights-and-measures-compliant net weight statements — add further obligations that vary by jurisdiction.

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North Carolina State University Extension Service, apiculture program publications. Covers processing, moisture management, and regional production; available at NC State Extension (ces.ncsu.edu).

Chapter 17. Hive Products – Wax, Propolis, Pollen, Royal Jelly & Venom

Covers exam questions Q309-Q320.

17.1 Orientation

The hive produces far more than honey. Beeswax, propolis, pollen, royal jelly, and venom are each distinct in chemistry, biology, and commercial application, and a master-level candidate is expected to understand all five at depth. The exam does not ask whether you know these products exist; it asks whether you understand how they are made at the cellular and colony level, what their composition tells you about their properties and risks, and how that chemistry translates into handling, storage, quality, and market requirements.

Two ideas organize most of what follows. The first is that the bee colony is a chemically sophisticated organism. Each product is the result of specific glands, specific age groups of bees, specific behavioral programs, and specific chemical transformations. Mistaking which gland makes which product, or which age group of bees performs which function, is a recurring exam error. The second organizing idea is that hive products are lipophilic accumulators. Beeswax, propolis, and to a lesser degree pollen concentrate fat-soluble compounds – including the miticides and pesticides that beekeepers and growers apply – far more efficiently than honey does. That single fact drives the most practically important guidance in this chapter: a beekeeper who produces or sells any of these products needs to know the treatment history of every colony contributing to them.

A third thread worth naming at the outset is perishability and storage. Royal jelly is among the most perishable of commercially harvested biological products; pollen is nearly as fragile; venom, once dried, is stable. Getting these products from colony to consumer in a form that retains their documented properties requires understanding what degrades them and how fast. The exam tests this understanding with specific handling temperatures and time constraints, not vague statements about “proper storage.”

17.2 Beeswax: Biology of Production

Beeswax is secreted by the four pairs of wax glands located on the ventral surface (sternites) of abdominal segments four through seven. These are sometimes called mirror glands because of the reflective appearance of the wax scales before they are worked. The glands are most active in worker bees roughly 12 to 18 days old – the stage that follows peak nursing (about days 4 to 12) and precedes foraging – and regress substantially as the bee transitions to field work. This age-dependence is important because it establishes that comb-drawing is the work of younger bees, not experienced foragers, and that a colony’s capacity to build comb is directly related to its population of young adults. A colony in a sudden strong flow will sometimes be short on wax-producing bees if too many of the young workers have been pressed into nectar receiving; a colony with an unusually young population following a large loss of foragers can draw comb rapidly.

Wax secretion occurs when the bee metabolizes sugars – primarily the sucrose and glucose in honey and nectar – and the fatty acids generated are assembled into the complex wax esters that are secreted through the gland cuticle as thin translucent scales. The bee picks the scale off with a leg spine, moves it to the mandibles, chews and works it (adding saliva and possibly small amounts of propolis), and deposits it on the growing comb. This metabolic transformation is energetically expensive, which is why the cost of comb matters to colony economics.

17.2.1 Chemical Composition

Beeswax is not a fat, a carbohydrate, or a protein. It is a complex mixture dominated by esters: monoesters, diesters, and hydroxy esters formed from long-chain fatty acids and long-chain alcohols. Free fatty acids, free alcohols, and a substantial fraction of hydrocarbons (paraffin-like straight-chain alkanes) are also present. This specific ester-dominated profile gives beeswax its characteristic chemical indices: an acid value around 17-24, an ester value around 70-80, and a saponification value around 87-102, depending on the assay method. These values are not arbitrary numbers; they are the chemical fingerprint of the ester chemistry, and they are what makes adulteration detectable.

The melting point of pure beeswax falls in a narrow range of approximately 144 to 149 degrees F (62 to 65 degrees C). This narrow range has two practical consequences. First, beeswax must never be rendered over direct flame; at temperatures above roughly 185 degrees F quality begins to degrade, and at higher temperatures the wax is flammable. Second, comb can approach its melting point inside a vehicle parked in summer heat in the southeastern US – a real and recurring cause of comb collapse that ruins both the wax and any honey it contained.

The specific gravity of beeswax is approximately 0.95 to 0.96, which is lighter than water, which is why rendered wax floats above the water layer when hot-water rendering is used and then solidifies as a cake that can be lifted free.

17.3 The Cost of Comb

The metabolic price of beeswax is a number every master-level beekeeper should be able to state and defend. Published estimates cluster around six to eight pounds of honey per pound of wax produced, though older references sometimes cite ratios as high as twenty to one. The wide range is not carelessness; it reflects genuine measurement difficulty. The metabolic cost depends on whether you count only the direct caloric cost of synthesizing wax esters from sugars or also include the cost of maintaining the wax-producing bees at comb-drawing temperature and the heat required to keep the fresh comb workable. Colony temperature, nutritional status, age structure, and whether the colony is already in a flow all affect the figure. No one has yet cleanly isolated comb-production metabolism in a working colony.

What the range does not affect is the management conclusion: drawing comb from foundation costs the colony honey, and drawn comb is therefore a capital asset. A colony entering spring with ten frames of drawn comb does not need to spend any honey starting new cells; it can devote the entire flow to filling the existing structure. That advantage compounds: the colony that is not drawing comb is also not keeping thousands of young bees occupied on that task rather than foraging. Protecting drawn comb

from wax moth, small hive beetle, mice, and rough handling is worth genuine effort. Discarding dark but sound comb because it looks old is a common and costly mistake.

Colonies draw comb most readily during a strong nectar flow when bees are young and numerous and the wax-secretion trigger is active. During a dearth, the same colony will typically refuse to draw foundation at all and may even begin cannibalizing wax from the outermost frames. This behavioral switch makes sense thermodynamically: the colony does not invest in capital during periods of negative cash flow.

17.4 Rendering Beeswax

17.4.1 Solar Rendering

A solar wax melter is an insulated glazed box tilted toward the sun, with a collecting pan at the lower end. Wax from cappings and light comb melts, flows through a screen or cloth, and collects in the pan. Solar rendering is efficient for cappings and lightly used comb, produces clean, light-colored wax with good aroma, requires no fuel, and suits the long-season solar resource in most of the US honey belt. Its limitations are weather-dependence and incomplete recovery: old dark comb leaves a substantial residue of insoluble organic material called slumgum – a mix of cocoon remnants, propolis, debris, and wax that does not melt cleanly – behind in the screen, and some wax is always lost in the slumgum.

17.4.2 Steam and Hot-Water Rendering

For larger quantities, especially old dark brood comb, steam or hot-water rendering is more practical. In the simplest form, comb is placed in water in a large stainless steel or aluminum vessel, heated until the wax melts, and then the liquid is strained and allowed to cool. The wax floats, solidifies as a cake, and is lifted free. The underside of the cake accumulates a layer of slumgum and impurities that is scraped off when cold. Steam kettles with a drain do the same job with better wax recovery and less mess.

17.4.3 Common Rendering Errors

Several errors reliably spoil a batch of wax, and the exam probes knowledge of them specifically:

Vessel material: Iron, copper, and brass react with beeswax and discolor it, producing a greenish or gray product that cannot be sold for cosmetics or candles. Use stainless steel, aluminum, or food-grade plastic containers.

Overheating: Temperatures above about 185 degrees F (85 degrees C) degrade wax quality, darken the color, and volatilize aroma compounds. Direct flame with an unwatched pot is the usual culprit.

Inadequate filtering: Wax run through a single layer of cheesecloth still carries fine particles of slumgum, pollen, and propolis. Filtering through multiple layers or a purpose-built wax filter bag is required for high-quality product. The wax must be filtered while hot enough to remain liquid.

Rapid cooling: Wax that cools too quickly in a cold mold traps water and debris in suspension and does not allow the dirty material to settle to the bottom where it can be scraped off. Insulating the mold with towels and cooling slowly gives cleaner wax.

Mixing comb grades: Cappings wax should be rendered separately from old brood comb. Cappings are clean, white, and carry far lower pesticide residues than dark brood comb that has supported many generations of larvae. Commingling the two grades contaminates the valuable cappings wax with residues and dark pigments that cannot be removed after the fact.

17.5 Wax Adulteration and Its Detection

Because beeswax commands a premium price, adulteration with cheaper substances is a persistent problem in the global wax market. Paraffin (a petroleum-derived hydrocarbon) and stearin (commercial stearic acid, a mixture of free stearic and palmitic acids derived from animal or vegetable fat) are the most common adulterants. Adulterated foundation has been associated with comb failure and, in some studies, with brood mortality, though the mechanisms are not fully characterized.

Detection relies on physicochemical indices. Paraffin introduces hydrocarbons with no ester or acid chemistry; it lowers the ester value and saponification value while the melting point may shift. Stearin introduces free fatty acids; it raises the acid value and changes the saponification value in a predictable direction. An experienced laboratory uses melting point, acid value, ester value, and saponification value together to characterize a sample and screen for adulteration, and gas chromatographic analysis of the hydrocarbon fraction adds another layer of specificity because the hydrocarbon profiles of beeswax, paraffin, and stearin are chemically distinct.

A beekeeper cannot detect adulteration by sight, smell, color, or touch. The only reliable screen is analytical chemistry. This is a practical reason to buy foundation from reputable suppliers with verified wax sourcing, particularly for operations where comb quality matters – queen rearing, comb honey production, and beeswax cosmetics marketed under a producer's name.

17.6 Residues in Beeswax: The Lipophilic Burden

Beeswax is the product most affected by the colony's chemical history, because it is lipophilic – fat-loving – and accumulates lipophilic compounds efficiently from the hive environment over years. Every survey of commercial US wax has found miticide residues, primarily tau-fluvalinate (from Apistan), coumaphos (from CheckMite+), and their respective metabolites. These compounds partition strongly into wax and remain there essentially indefinitely; they do not dissipate with time. Dark old brood comb accumulates the highest concentrations because it has been exposed to more treatment cycles.

The practical consequences are two. First, because commercial foundation is manufactured from pooled recycled wax collected from many operations, residues from a producer who used heavy miticide applications circulate into the foundation used by beekeepers who made different choices. A beekeeper who has never applied coumaphos can still find it in comb drawn from commercial foundation. Second, laboratory studies have demonstrated sublethal effects on queens and drones at concentrations found in wax from managed colonies. In a mating nucleus or cell-builder box, this is not a trivial concern: if grafted queens or emerging drones are exposed to residues in the comb during critical developmental periods, the outcome may be diminished queen quality or drone fertility with no visible cause.

The practical responses are: cull old dark brood comb on a rotation (the common target is about 20 percent of brood comb a year, a five-year cycle, with one-third a year in more aggressive programs; Chapter 6), segregate cappings wax from brood comb wax at rendering, and consider residue-tested or cappings-derived foundation for queen-rearing operations where comb quality matters most.

17.7 Propolis: Composition, Function, and Collection

17.7.1 What Propolis Is

Propolis is not a bee secretion in the way that beeswax or royal jelly is. It is a collected plant resin – gathered primarily from the bud scales of trees (poplars, birches, horse chestnuts, and various conifers are common sources) and from wounds in bark – carried home on the field bee's corbiculae (pollen baskets) and mixed in the hive with wax, mandibular secretions and small amounts of pollen. The result is a sticky, resinous material whose exact composition varies substantially with the plant community where the bees forage. Temperate-zone propolis in Europe and North America is typically the poplar-beeswax type. The once-standard figures for it (roughly 50 to 60 percent resins, 30 to 40 percent waxes, 5 to 10 percent essential oils) trace to un-rigorous pre-1934 sources and are not supported by modern quantitative analysis: measured samples typically run resin above 70 percent, wax well under 30 percent (commercial-grade propolis is generally rejected above 25 percent wax), and essential oils and other volatiles usually under 10 percent and often under 1 percent, with a small fraction of pollen and organic debris. Tropical propolis types differ markedly: Brazilian green propolis, derived primarily from Baccharis dracunculifolia, has a distinctive chemistry dominated by prenylated cinnamic acid derivatives such as artepillin C; red propolis from certain mangrove regions is chemically distinct again. No single specification describes propolis generally, which matters enormously to anyone marketing it.

17.7.2 Functions in the Colony

The colony uses propolis for mechanical and biological purposes simultaneously. Mechanically, it seals cracks and crevices, reduces entrance size, and coats rough surfaces and joints, stabilizing the hive structure and reducing air movement and vibration. Biologically, propolis varnishes the interior surfaces of the hive – including the inside surfaces of cells – with a thin antimicrobial layer. The flavonoids, phenolic acids, and terpenes in propolis have demonstrated activity against gram-positive bacteria, various fungi, and some viruses. The protection is most reliable against gram-positive organisms; gram-negative bacteria are less reliably affected. In high concentrations near the brood nest, propolis also contributes to the "propolis envelope" that bees construct on the inner surfaces of the cavity. When an intruder too large to remove – a mouse or a small lizard – dies inside the hive, bees encase the carcass in propolis to prevent decay and the microbial load it would bring.

Research published in the last two decades has shifted the beekeeper's view of propolis from nuisance to asset. Studies have found that colonies given a propolis envelope – by stapling propolis traps to the inner walls or by using rough interior surfaces that encourage deposition – show lower, more uniform baseline expression of immune-related genes (Borba et al., 2015) – the colony's baseline immune investment is lower when the propolis envelope does some of that work. Earlier work (Simone et al., 2009) showed that propolis extracts reduced the expression of some immune genes and lowered

bacterial loads. This does not mean propolis replaces the bees' immune system, but it suggests that natural cavity conditions (with extensive propolis lining) represent the evolved normal for the species. Some beekeepers now roughen hive interiors deliberately or add textured surfaces to encourage propolis deposition.

17.7.3 Geographic and Genetic Variation

Caucasian bees (*Apis mellifera caucasica*) are known for particularly heavy propolis collection and use; other stocks collect much less. This is a heritable trait and is one reason Caucasian genetics appear in some breeding programs aimed at enhanced disease resistance and in others are avoided because the resulting hive management difficulty is not acceptable to all beekeepers. From a product standpoint, the genetic background of the colony affects not only the quantity but, because it influences which plant sources the bees prefer, potentially the chemical composition of the propolis collected.

17.7.4 Harvesting: Traps vs. Scraping

The quality difference between trap-harvested and scraped propolis is large enough that any beekeeper selling propolis should understand it clearly.

A propolis trap is a flexible plastic mesh mat or a slotted plastic screen placed on top of the frames, under the inner cover or outer cover, positioned so that a small amount of light enters around the edges. The bees interpret the openings in the trap as cracks to seal and fill them with propolis. To harvest, the mat is removed and chilled or frozen, which makes the propolis brittle; once frozen, the mat is flexed and the propolis fragments fall free or are knocked out into a collection container. The resulting material consists almost entirely of pure propolis with the trace wax naturally present in the material itself.

Scraped propolis – the material collected from the faces of frames, the rabbet of boxes, the inside of covers, and any other joint the bees have sealed – is unavoidably contaminated with wood fibers, paint chips, caulk, wax, and assorted hive debris. Cleaning it adequately for human use requires labor that offsets much of the apparent advantage in yield. For any cosmetic, supplement, or food use, trap propolis is the appropriate starting material.

Because propolis is lipophilic, it concentrates pesticide residues just as wax does. A propolis producer should maintain records of treatment history for contributing colonies, and the argument for using colonies with known clean histories is at least as strong for propolis as for cappings wax.

17.8 Pollen: Collection, Handling, and Nutritional Value

17.8.1 The Colony's Perspective

Pollen is the colony's primary protein source, providing the amino acids essential for larval development, hypopharyngeal gland function in nurse bees, and the synthesis of vitellogenin in workers. Crude protein content varies widely by plant source, ranging from roughly 10 percent in some plants to 40 percent or more in others; foragers draw on many species, and their preferences appear to track the protein-to-lipid balance of the pollen rather than protein alone. Pollen also delivers lipids,

carbohydrates, vitamins, sterols, and various phytochemicals that support immune function and longevity.

Bee bread is pollen that workers have packed into cells and mixed with honey and glandular secretions. The additions drop the pH to around 4 and, with a honey seal excluding air, suppress spoilage organisms, so bee bread keeps for months where fresh pollen molds within days (Chapter 8). The current evidence describes this as preservation, with lactic acid bacteria contributing, rather than a fermentation that predigests the pollen; nurse bees actually prefer fresher stored pollen, and stored pollen loses nutritional value with time. When beekeepers feed trapped pollen back to colonies, the bees pack and preserve it the same way.

17.8.2 Trapping

Pollen traps intercept foragers returning with full corbiculae (pollen baskets) and strip the loads from their legs as they pass through a screen or a series of small openings. The stripped pellets fall into a collection tray. Several trap designs exist: bottom-board traps mounted at the entrance, top-board traps, and side traps that mount in the hive body. All designs face the same tradeoff: the trap removes pollen the colony needs, so continuous operation depletes the colony's protein reserve and can cause brood rearing to collapse. Standard guidance is to trap intermittently – for a few days at a time with trap-free periods in between, and only on strong colonies in a good flow – and never on a colony already showing signs of nutritional stress (spotty brood, slow population growth, failure to draw comb). A colony with capped honey stores well below adequate going into a trap period is a colony that should not be trapped.

17.8.3 Handling and Preservation

Fresh pollen is highly perishable because it carries substantial moisture and an active microbial community. In warm, humid weather – which describes summer in much of the southeastern US – pollen in a collection tray will begin to mold or ferment within hours. The standard handling protocol is: empty traps daily (or more frequently in peak flow), remove visible debris and dead bees, and either dry the pollen or freeze it without delay.

Drying is done at low temperature to preserve nutritional quality. The generally cited maximum is approximately 105 to 113 degrees F (40 to 45 degrees C), with dry moving air. At higher temperatures, enzymes are denatured, some volatile bioactive compounds are lost, and moisture damage to amino acids begins. Properly dried pollen (moisture content about 6 percent or less) can be stored at room temperature for months in airtight packaging, though freezing is preferable for long-term storage. Fresh undried pollen should be considered a perishable food requiring refrigeration, and even under refrigeration its quality degrades within days. Freezing immediately after drying is the most reliable way to maintain nutritional quality until sale or use.

17.8.4 Pollen in the Broader Context

Pollen sold for human consumption is marketed as a health food with a range of claimed benefits. The allergenic potential is real and should be disclosed to consumers; some individuals experience significant

reactions to bee-collected pollen, particularly those already sensitive to the plant species represented. No prescription is required for pollen sales in the US, and the marketplace quality is highly variable.

Pollen analysis – melissopalynology – is a distinct discipline that deserves mention at master level because it underlies botanical verification and geographic origin determination of honey. Each plant species produces morphologically distinctive pollen grains, and because pollen from the nectar sources bees visit ends up in honey, the pollen assemblage in a honey sample is a botanical and geographic record. Melissopalynological analysis is used by food scientists and regulators to verify varietal honey claims (is this actually buckwheat honey?) and to detect geographic fraud (honey labeled as domestic that contains a pollen assemblage consistent only with certain foreign agricultural regions). A candidate who understands why this works – because pollen morphology is species-specific and survives in honey – is prepared for questions about honey authenticity as well as pollen collection.

17.9 Royal Jelly: Production, Harvest, and Perishability

17.9.1 Glands and Age Group

Royal jelly is produced by the hypopharyngeal glands and the mandibular glands of young nurse bees, typically in the range of five to fifteen days old. This overlaps the early wax-secreting ages but is not the same peak, since nursing comes earlier. The hypopharyngeal glands, which develop fully only in well-nourished young bees, produce the protein-rich component; the mandibular glands contribute lipid components and, in the case of royal jelly, the distinctive fatty acid 10-hydroxy-2-decenoic acid (10-HDA). Both glands must be active and functional to produce normal royal jelly, which is why queen-rearing operations feed protein supplements when incoming pollen is insufficient – gland function declines rapidly in protein-deficient bees.

It is a common and serious error to attribute royal jelly production to the wax glands. The wax glands are on the abdomen, are responsible exclusively for wax secretion, and have no role in royal jelly. The hypopharyngeal and mandibular glands are in the head. These are anatomically and functionally distinct systems that are active at overlapping ages.

17.9.2 Composition

Royal jelly is approximately 60 to 70 percent water, 12 to 15 percent protein, 5 to 6 percent fatty acids, 10 to 16 percent sugars, and small amounts of minerals and vitamins. The protein fraction is dominated by the major royal jelly proteins (MRJPs), a family found chiefly in royal jelly; the most abundant, MRJP1, was named royalactin in a 2011 study that claimed it alone triggers queen development, a claim later studies have not upheld. The fatty acid fraction includes 10-HDA, which is present in fresh royal jelly at levels of approximately 1.4 percent or more of the total material and is the signature compound used as a quality and authenticity marker. 10-HDA has documented antimicrobial activity, hormonal effects in bees, and is measured in every serious quality assessment of royal jelly product. A low 10-HDA value points mainly to adulteration or substitution. It changes little in storage, so freshness is judged by other indicators such as furosine, 5-HMF, color, and enzyme activity.

17.9.3 Harvest Timing

Commercial royal jelly is harvested from queen cells. The production sequence is: graft young larvae (typically 12 to 24 hours old) into cell cups, introduce them to a queenless or queen-right starter/finisher colony, and allow the nurse bees to provision the cells with royal jelly over approximately 68 to 72 hours. At that point, the larvae have consumed relatively little of the jelly provided, and the cells contain the maximum quantity of harvestable product – typically 150 to 350 milligrams per cell in a well-provisioned operation. The larvae are removed, and the jelly is aspirated or scooped from each cell. Waiting longer means the larva consumes more jelly and yields decline; harvesting earlier means the nurse bees have not had time to provision fully.

This is why royal jelly is harvested from queen cells, not worker cells. Worker larvae receive royal jelly for only the first two or three days of larval life in quantities an order of magnitude smaller than what a queen larva receives throughout; the quantity in a worker cell at any point is not commercially harvestable, and the product in a worker cell at later larval stages is a different mixture (worker jelly) rather than the full queen-destined composition.

17.9.4 Storage and Perishability

Royal jelly is among the most perishable products harvested from the hive. At room temperature, quality degrades steadily over days to months: enzyme activity continues post-harvest (breaking down proteins and fatty acids), furosine and 5-HMF rise (10-HDA itself changes little), pH changes, color darkens from white or pale cream toward amber, and microbial growth begins. Any claim that fresh royal jelly is stable at room temperature for weeks or longer is false. Proper immediate storage is refrigeration at 2 to 4 degrees C for short-term holding (days to a few weeks) or freezing at -18 to -20 degrees C for longer storage. Light accelerates degradation and should be excluded.

Freeze-drying (lyophilization) is the preferred preservation method for royal jelly intended for long-term sale or export because it removes water without heat, preserving the protein and fatty acid fractions and maintaining 10-HDA at close to fresh levels. Spray-dried or warm-dried royal jelly is markedly inferior in quality. Fresh refrigerated royal jelly is the preferred form for apitherapy users who want the fully intact product, but it requires cold-chain management from hive to consumer.

China dominates global commercial royal jelly production – producing roughly 85 to 90 percent of world supply – because the harvest is labor-intensive (each cell must be individually worked) and the wage structure in China makes the operation economically viable at large scale. Small-scale royal jelly production is feasible for a US beekeeper who already operates a queen-rearing program, since the infrastructure is largely shared.

17.10 Bee Venom: Composition and Collection

17.10.1 What Venom Contains

Bee venom is a complex mixture of proteins, peptides, enzymes, and small molecules. The dominant component by dry weight is melittin, a 26-amino acid peptide that constitutes roughly 50 percent of dry venom. Melittin is membrane-disrupting: it integrates into lipid bilayers and causes cell lysis, which is

the mechanism responsible for the immediate pain and local tissue destruction after a sting. The next most abundant component is phospholipase A2 (PLA2), at roughly 10 to 12 percent of dry venom. PLA2 hydrolyzes the phospholipid components of cell membranes, amplifying the damage melittin initiates; it is also the primary allergen responsible for IgE-mediated allergic reactions. Smaller components include apamin (a neurotoxin affecting potassium channels), adolapin (which has anti-inflammatory properties in some assay systems), histamine (a small fraction of the venom), and other minor peptides and enzymes.

A fact often confused at exam level: the severe systemic allergic reaction to bee stings is not primarily a histamine effect even though histamine is present in venom. The histamine content of bee venom is too small to account for anaphylaxis. True anaphylaxis is an IgE-mediated immune response – the sensitized individual's immune system recognizes venom proteins (especially PLA2) and triggers a massive release of histamine and other mediators from mast cells and basophils throughout the body. This is qualitatively different from local histamine release at the sting site. The treatment for anaphylaxis – epinephrine – targets the systemic cardiovascular and bronchospasm effects; antihistamines alone are insufficient.

17.10.2 Stings and the Venom Sac

When a honey bee stings a vertebrate, the barbed sting typically embeds in the skin and is autotomized – torn from the bee – as the bee pulls away. The sting apparatus, including the venom sac and the associated muscles, remains in the skin and continues to pump venom by muscular action for up to a minute, delivering roughly 90 percent of its venom in the first 20 seconds or so. The amount of venom injected therefore depends on how quickly the sting is removed. The method does not matter: a small experiment in which volunteers stung themselves (Visscher, Vetter and Camazine, 1996) found that the size of the resulting weal rose with the time the sting stayed in and did not differ between scraping and pinching. Remove it at once by whatever means is fastest; a fingernail or hive tool edge is convenient, but hunting for one costs more venom than a pinch (Chapter 19).

17.10.3 Commercial Venom Collection

The standard method for commercial venom collection places a collector unit at the hive entrance. The device consists of a thin wooden or plastic frame with electrical wires spaced at intervals that deliver brief, low-current pulses when bees contact them, and beneath the wires a glass or Teflon collection surface. The mild shock stimulates the bees to sting the surface. Because the surface is smooth and does not grip the barbs as skin does, the bee withdraws the sting and survives. The venom deposited on the collection surface dries within minutes into a pale, waxy powder. The collector is removed periodically, the dried venom scraped or peeled from the surface, and the raw material frozen for storage or further processing.

This method has real operational consequences. Colonies exposed to venom collector stimulation become markedly more defensive for a period – the alarm pheromone released with it (isoamyl acetate, from the sting apparatus) alerts guard bees, and repeated stimulation can put a colony on heightened alert for hours or days. Venom collection should not be done near the public, near animals, or on apiaries where temperament is being managed for other purposes. The dried venom powder itself is a

serious respiratory hazard; inhalation of even small amounts can cause sensitization and subsequent anaphylaxis in operators. Appropriate respiratory protection (an N95 or better respirator) and skin protection are required.

17.10.4 Uses of Venom

Venom immunotherapy (VIT) – desensitization of sting-allergic individuals by injecting progressively larger doses of purified venom – is an evidence-based medical treatment with a robust clinical literature demonstrating efficacy. For individuals with documented IgE-mediated sting allergy, VIT reduces the risk of future anaphylaxis dramatically. This is medically distinct from apitherapy.

Apitherapy encompasses a range of uses of bee products – including whole bee stings applied deliberately – for conditions including arthritis, multiple sclerosis, and various chronic pain syndromes. The research base is uneven. Some anti-inflammatory and analgesic properties of venom components (particularly apamin and adolapin) are documented in laboratory systems. Clinical trials in humans are limited in number, size, and rigor. A master beekeeper asked about apitherapy should be able to articulate both what practitioners claim and what the evidence currently supports, without dismissing the entire field or overstating the clinical evidence. That calibrated answer – knowing where certainty ends – is what the exam rewards. Melittin is also under active investigation as a platform for drug delivery, since its membrane-disrupting properties can be directed at specific cell types, including cancer cells, by attaching targeting molecules.

17.11 Hive Products and Treatment History: The Residue Problem

Honey is largely an aqueous solution of sugars and carries relatively few lipophilic compounds. Beeswax, propolis, and pollen are lipophilic matrices and concentrate fat-soluble compounds orders of magnitude more efficiently. Surveys have consistently found miticide residues in commercial US wax at concentrations far exceeding those in honey from the same hives. Rendering wax does not remove residues; they are dissolved in the wax fraction and remain after slumgum is removed. Drying pollen does not remove residues; it concentrates them by removing water. No step in the processing of these products volatilizes or destroys lipophilic organic compounds.

This is the single most practically important fact in this chapter for a producer of non-honey hive products. A beekeeper who sells beeswax cosmetics, propolis for human use, or trapped pollen is selling products whose chemical history reflects everything applied to or exposed to by the contributing colonies, going back years in the case of wax in old comb. The producer who does not know that history cannot make a sound decision about what product is appropriate for what use.

The professional response is recordkeeping: what was applied, to which colonies, in what quantities, on what dates. It is also strategic: segregating cappings wax (consistently the cleanest fraction) from brood comb wax, avoiding application of lipophilic miticides to colonies contributing to wax or propolis products if alternatives are available, and cycling out old comb on a regular schedule so that accumulated residues do not compound indefinitely.

Selling beeswax cosmetics and candles requires understanding additional regulatory and business considerations. Candles are consumer products subject to general product safety expectations and, in

some jurisdictions, specific labeling requirements (warning language about keeping wicks trimmed, not burning near flammables). A balm or salve applied to skin is a cosmetic under US law and requires ingredient labeling in descending order of predominance, net contents, and producer identification. If the labeling makes therapeutic claims – that the product heals wounds, reduces inflammation, or treats any condition – it becomes a drug and triggers far more stringent requirements that a small producer cannot generally meet. Since the Modernization of Cosmetics Regulation Act of 2022 (MoCRA), anyone marketing a cosmetic in the United States must also be able to substantiate its safety, report serious adverse events to FDA within 15 business days, and give on the label a US address, telephone number or electronic contact through which consumers can report adverse events. Small businesses - broadly, those averaging under about one million dollars a year in US cosmetic sales - are exempt from facility registration, product listing and the manufacturing-practice rules, but not from safety substantiation, adverse-event reporting or the label contact. Business operations require lot coding for traceability (to recall a specific batch if a problem is identified), liability insurance, and familiarity with applicable state cosmetic manufacturing and home-based business regulations, which vary substantially across the country.

17.12 Numbers to Know Cold

Figure	Value	Why it is that value
Wax gland location	Ventral sternites, abdominal segments 4-7	These are the “mirror glands”; wax scales form on the cuticle here
Peak wax-gland activity (worker age)	Approximately 12-18 days old	Follows peak nursing (about days 4-12); glands regress as bees shift to foraging
Metabolic cost of wax	~6-8 lb honey per lb wax (range in literature to ~20:1)	Sugars are metabolized into fatty acids and assembled into esters; the range reflects measurement difficulty, not fundamental disagreement
Beeswax melting point	~144-149 degrees F (62-65 degrees C)	Ester chemistry produces this characteristic narrow range
Beeswax specific gravity	0.95-0.96	Slightly lighter than water; wax floats in hot-water rendering
Propolis composition (temperate)	Resin often >70%; wax usually <30%; essential oils usually <10% (often <1%)	Plant source determines exact proportions; the older ~50-60/30-40/5-10 figures are a documented pre-1934 myth, not measured data
Pollen drying temperature maximum	~105-113 degrees F (40-45 degrees C)	Above this, enzymes denature and nutrients degrade
Pollen moisture for storage	About 6% or less	Prevents mold and fermentation at room temperature
Royal jelly water content	~60-70%	High water content drives perishability
Royal jelly protein content	~12-15%	Primarily major royal jelly proteins (MRJPs/royalactins)

Figure	Value	Why it is that value
10-HDA content (fresh royal jelly)	~1.4% or more of total weight	Signature fatty acid; quality/authenticity marker (adulteration lowers it); changes little in storage
Optimal harvest time (queen cells)	~68-72 hours post-grafting	Maximum jelly accumulation before larva consumes significant volume
Royal jelly short-term storage	2-4 degrees C (refrigerator)	Slows enzymatic degradation and microbial growth for days to weeks
Royal jelly long-term storage	-18 to -20 degrees C (freezer)	Arrests degradation; preferred for extended storage
Melittin fraction of dry venom	~50%	Dominant component; responsible for membrane disruption and immediate pain
Phospholipase A2 fraction	~10-12% of dry venom	Primary allergen for IgE-mediated reactions; amplifies melittin damage
Venom sac pump duration (after sting)	Up to ~1 minute (~90% delivered in the first ~20 seconds)	Autotomized sting continues pumping; removal speed matters
Wax acid value	~17-24	Ester chemistry sets this; paraffin has no acid value; stearin raises it
Wax ester value	~70-80	Diagnostic fingerprint; used with acid and saponification values to detect adulteration

17.13 Common Misconceptions

Misconception: Experienced forager bees make the most wax because they are older, stronger, and have been in the colony longest. **Correction:** Wax glands are most active in bees approximately 12 to 18 days old – the stage after peak nursing. The glands begin to regress as bees transition to foraging at around three weeks of age. A hive full of experienced foragers is a hive with diminished wax-producing capacity, not enhanced capacity.

Misconception: The metabolic cost of wax means a colony on foundation never profits from the nectar flow until the comb is fully drawn. **Correction:** The cost is real but the picture is more nuanced. A colony begins to store honey as soon as cells are complete, even while other bees are drawing adjacent cells. The cost of comb drawing is a drag on net honey accumulation, not a moratorium on it. The point is that a colony with drawn comb nets more from the same flow.

Misconception: Rendering beeswax removes pesticide residues, so rendered wax is clean regardless of the source material. **Correction:** Rendering separates wax from slumgum and debris, but lipophilic pesticide residues (fluvalinate, coumaphos, and their metabolites) are dissolved in the wax phase and remain in the finished product at essentially the same concentration as in the raw material. Source quality determines product quality; processing cannot undo contamination.

Misconception: Any metal pot can be used for wax rendering as long as it is clean. **Correction:** Iron, copper, and brass all react with beeswax and produce discoloration – typically greenish or gray tones – that cannot be removed. Stainless steel, aluminum, and food-grade plastic are the appropriate vessel materials for wax work.

Misconception: Propolis is nothing more than a nuisance that beekeepers should try to minimize because it makes hive management difficult. **Correction:** Research has established that propolis contributes meaningfully to colony health. The propolis envelope on interior hive surfaces provides antimicrobial activity that reduces the colony's baseline immune load, as measured by immune gene expression. Colonies given a propolis envelope show lower, more uniform baseline immune-gene expression than colonies without one (Borba et al., 2015). Propolis is also the colony's primary means of entombing large intruders and sealing structural gaps.

Misconception: Scraped propolis is perfectly adequate for human use because the propolis content is the same as in trap-collected material. **Correction:** Scraped propolis is contaminated with wood fibers, paint, metal fragments, caulk, wax, and general hive debris that is impractical to remove completely. Trap-collected propolis, harvested by freezing and flexing a plastic mesh mat, is essentially pure propolis with no adventitious materials.

Misconception: Royal jelly is produced by the wax glands of nurse bees, the same glands that produce beeswax. **Correction:** Royal jelly is produced by the hypopharyngeal glands and mandibular glands, both of which are in the head. The wax glands are on the ventral surface of the abdomen and produce wax exclusively. The two systems are active at overlapping ages of bees but are anatomically distinct and produce entirely different products.

Misconception: Royal jelly can be stored at room temperature for extended periods without significant quality loss, like honey. **Correction:** Royal jelly is highly perishable. At room temperature, enzyme activity continues post-harvest, protein fractions break down, furosine and 5-HMF rise, pH changes, color darkens, and microbial growth begins; the loss is progressive over days to months. It requires immediate refrigeration (2 to 4 degrees C) for short-term storage or freezing for any extended period. It is nothing like honey in stability.

Misconception: Severe allergic reactions to bee stings are caused by the histamine in venom. **Correction:** Anaphylaxis is an IgE-mediated immune response. The allergen is primarily phospholipase A2 (PLA2); a sensitized person's immune system triggers massive mast-cell degranulation and systemic histamine release from their own cells – far exceeding the small amount of histamine in the venom itself. The venom's histamine content is pharmacologically trivial in the context of anaphylaxis.

Misconception: A sting must always be scraped out, never pinched, because pinching squeezes the venom sac and injects the rest of the venom. **Correction:** Small experimental evidence found that the reaction depends on how long the sting stays in, not on the removal method. Remove it at once by the fastest means available, pinching included; delay while looking for a hive tool is the real error (Chapter 19).

Misconception: Bee bread is fermented, predigested pollen, so it is more nutritious than fresh pollen and trapped pollen is a poor substitute. **Correction:** Bee bread is pollen preserved by the honey and glandular secretions the bees add, which drop the pH and suppress spoilage; lactic acid bacteria participate, but the evidence does not support predigestion, and nurse bees prefer fresher stored pollen. Trapped pollen fed back to a colony is packed and preserved the same way; its limits as a supplement come from drying and storage losses and from disease risk if it came from other colonies, not from missing fermentation.

Misconception: A beekeeper can rely on treatment choice alone to keep hive products residue-free; the products themselves tell you nothing. **Correction:** Residue history accumulates in wax over multiple treatment cycles and years. Dark old comb may carry the residue history of the previous beekeeper, the foundation manufacturer, and every treatment applied to the colony in the intervening years. A beekeeper who does not cull old comb, segregate cappings wax, and maintain treatment records cannot make defensible claims about residue status regardless of current practices.

17.14 Self-Check Questions

- Explain the anatomical basis for the rule that wax-producing capacity is concentrated in young bees. What happens to the wax glands as a bee ages, and what does this mean for a colony's ability to draw comb in late summer when the population is skewed toward older foragers?
- A beekeeper claims their small-scale rendering operation produces wax as clean as commercial cappings wax, even though they melt old dark brood comb and cappings together. Identify the specific error in this practice and explain why it cannot be corrected downstream in the rendering process.
- You are purchasing beeswax foundation from an unfamiliar supplier and want to know whether it is adulterated with paraffin. What tests would a laboratory perform, and what specific results would indicate paraffin adulteration? Why can you not detect this by sight or smell?
- Describe the mechanism by which a propolis trap produces a product superior to scraped propolis. What triggers the bees to fill the trap? What does the harvesting procedure (freezing + flexing) accomplish?
- Distinguish bee bread from trapped fresh pollen on three axes: production process, nutritional profile, and appropriateness for feeding back to colonies.
- A beekeeper in your local association says she runs her pollen traps continuously from April through July to maximize yield. Identify the specific risk to the colony this creates and describe a trapping schedule that manages that risk. What environmental conditions particular to the southeastern US make the handling side of continuous trapping especially problematic?
- Royal jelly is harvested from queen cells at approximately 68 to 72 hours post-grafting. Explain why this specific window is chosen rather than harvesting at 24 hours or at 96 hours.
- Identify the three errors embedded in the claim that "royal jelly is produced by the wax glands, harvested from worker cells, and can be stored in the refrigerator door for a year without quality loss."

- A sensitized individual is stung once and develops throat tightening, widespread hives, and a drop in blood pressure within ten minutes. Explain the immunological mechanism responsible, and identify which venom component is most likely the primary trigger. Is this a toxic reaction or an allergic reaction, and why does the distinction matter clinically?

- You are setting up commercial venom collection at a ten-hive apiary. Describe the hardware used, the effect on colony temperament after a collection session, and two specific safety precautions required for the operator during the collection and processing of dried venom.

- You plan to sell a beeswax balm at a farmers market. List four distinct considerations – spanning product safety, legal labeling, wax quality, and business operations – that you must address before your first sale.

- Rank the following hive-derived materials in approximate order of their lipophilic pesticide residue concentration, from highest to lowest, and explain why the ranking is what it is: honey, cappings wax, old brood comb wax, propolis, fresh pollen.

17.15 Self-Check Answers

- The wax glands (mirror glands) are exocrine glands on the ventral sternites of abdominal segments four through seven that reach full functional size and secretory activity in bees roughly 12 to 18 days old – the stage that follows peak nursing. As the bee shifts to foraging at around three weeks, the glands undergo partial regression: secretory cell volume decreases, and wax output drops substantially. In late summer following a heavy flow, populations skew toward older foragers who have outlasted the spring cohort of young bees; the colony's wax-producing capacity is therefore lower per adult bee even if total colony size is adequate. A colony that cannot rapidly replace forager losses with new bees from the brood nest will have a reduced comb-building capacity during fall buildup for winter.

- Old dark brood comb carries accumulated lipophilic pesticide residues – primarily fluvalinate (Apistan residues), coumaphos (CheckMite+ residues), and their metabolites – that have accumulated over multiple brood cycles and treatment applications. When dark comb is melted together with cappings, those residues dissolve into the liquid wax pool and mix uniformly with the clean cappings wax. Rendering separates wax from slumgum and insoluble debris, but it does not remove dissolved lipophilic compounds, which remain in the wax fraction at their proportional concentration. The contamination is permanent and cannot be extracted, filtered, bleached, or otherwise removed from the finished wax block.

- A laboratory would measure four physicochemical indices: melting point (paraffin typically melts lower than pure beeswax), acid value (paraffin contributes essentially no acid value, so blending it dilutes the acid value of the mixture), ester value (same dilution effect), and saponification value. The ratios of these values to each other provide additional diagnostic power. Gas chromatographic analysis of the hydrocarbon fraction is definitive: beeswax shows a strong predominance of odd-numbered n-alkanes (mainly C27, C29, and C31) with only minor even-numbered chains, whereas paraffin contains odd and even n-alkanes in near-equal amounts and extends to chain lengths (above about C33 to C35) that pure beeswax does not contain. Added paraffin raises the even-numbered peaks and introduces these long chains. Color and odor cannot distinguish adulterated from pure wax because paraffin is odorless and colorless; a

skilled adulteration can produce a product that passes visual and sensory inspection while failing chemical analysis.

- The trap is a flexible plastic mesh mat or slotted screen with openings too small for bees to pass through, placed on top of the frames under the cover, usually with a crack admitting light. Bees interpret the multiple small openings as structural gaps that need sealing – the same stimulus that causes propolis deposition in joints and cracks throughout the hive. They fill the openings with propolis over days to weeks. To harvest, the mat is removed, frozen until the propolis becomes glassy-brittle (propolis is thermoplastic; it is flexible and sticky at warm temperatures and fractures cleanly when cold), and then flexed sharply. The propolis breaks free in small pieces that fall into a clean container. The resulting product is pure propolis because the bees deposited only propolis into the openings; no wood, paint, metal, or general debris is included, unlike scraping from hive surfaces where all of those contaminants are inevitably collected.

- **Production process:** Bee bread is pollen that workers pack into cells and mix with honey and glandular secretions, usually sealed under a film of honey. The additions acidify it to about pH 4 and exclude air; lactic acid bacteria participate, but the process is preservation rather than a fermentation that digests the pollen. Trapped pollen is stripped mechanically from returning foragers and has had none of these additions. **Nutritional profile:** The nutrients are those of the pollen itself; bee bread is not predigested or made more bioavailable, and its value declines with storage time, which is why nurses prefer fresher stored pollen. Trapped pollen that is promptly dried or frozen keeps much of its value. **Appropriateness for feeding colonies:** Trapped pollen can be fed back as a protein supplement, and the bees will pack and preserve it as bee bread; the cautions are disease risk if it comes from other colonies and nutrient losses from poor drying or long storage.

- Continuous trapping removes pollen the colony needs for larval rearing; a colony under sustained pollen stress will reduce brood rearing, have undersized hypopharyngeal glands in nurse bees (reducing their capacity to produce brood food), and may fall below the population needed for a productive wintering cluster. A managed schedule – trap for a few days at a time with trap-free periods in between, inspect the colony weekly for brood pattern and pollen stores, and halt trapping entirely if stored pollen is not visible in at least two frames adjacent to the brood – prevents the depletion. In the southeastern US the handling problem is acute because summer temperatures and humidity accelerate spoilage: pollen in a warm, humid tray molds within a few hours. Daily trap emptying is a minimum; in hot weather, twice-daily emptying followed by immediate refrigeration or freezing is closer to the appropriate interval.

- The 68 to 72 hour window is chosen because it represents the maximum accumulation of royal jelly before the larva begins consuming it faster than the nurse bees replenish it. At 24 hours, nurse bees have had insufficient time to provision the cell to maximum volume. At 96 hours or later, the larva is larger and has been consuming jelly actively; remaining volume and freshness decline. The window also coincides with the larval age at which differentiation into queen developmental pathway is becoming irreversible, after which the quantity of jelly begins to decline on its own. Commercially, the 68 to 72 hour harvest maximizes yield per cell while maintaining product quality.

- The three errors: (1) Royal jelly is produced by the hypopharyngeal and mandibular glands in the head, not the wax glands, which are abdominal sternite structures that produce only beeswax. (2) Commercial royal jelly is harvested from queen cells, not worker cells; worker cells contain

only trace quantities of the provisioning material, which is a different mixture than queen jelly and is not present in harvestable volume. (3) Royal jelly is highly perishable and requires refrigeration at 2 to 4 degrees C for short-term storage or freezing at -18 to -20 degrees C for extended periods; at room temperature, quality degrades progressively through enzymatic breakdown, microbial growth, and the buildup of deterioration markers such as 5-HMF and furosine. A year at room temperature would leave a degraded, microbiologically unsafe material bearing little resemblance to fresh royal jelly.

- The reaction is IgE-mediated anaphylaxis, a true allergic reaction. The sensitized individual previously encountered bee venom (in a prior sting) and mounted an immune response that produced IgE antibodies specific to venom proteins. Phospholipase A2 is the primary allergen – the venom component that most commonly triggers IgE sensitization. On re-exposure, PLA2 cross-links IgE on mast cells and basophils throughout the body, triggering rapid degranulation and systemic release of histamine, leukotrienes, and other mediators from the person's own immune cells. This produces vasodilation, bronchospasm, and hypotension within minutes. This is clinically distinct from a toxic reaction (which is dose-dependent and can occur in any person given enough stings) because anaphylaxis occurs after a single sting in a sensitized individual and is immunologically mediated, not a direct pharmacological effect of the venom dose. The distinction matters because the treatment is epinephrine (which counters vasodilation and bronchospasm) rather than simply treating local swelling.

- The hardware is a collector unit placed at the hive entrance: a frame with parallel electrified wires above a glass or Teflon collection surface. A timer-controlled intermittent current (brief pulses) stimulates bees landing on the grid to sting the underlying surface; because the surface does not grip the sting barbs as skin would, the bee withdraws and survives. Venom deposits on the collection surface and dries within minutes. After a collection session, colonies are substantially more defensive – the iso-amyl acetate alarm pheromone in the deposited venom alerts guard bees, and the colony may remain on heightened alert for hours or longer. Collections should not be done when the public or animals are nearby. Operator safety precautions: (1) respiratory protection (N95 or better respirator rated for fine particulates) is essential because dried venom powder is a serious respiratory allergen and inhalation can cause sensitization and subsequent anaphylaxis; (2) skin and eye protection, including a full beesuit and face shield, because the powder becoming airborne during scraping can settle on skin and mucous membranes.

- **Product safety and labeling (legal):** A beeswax balm applied to skin is a cosmetic under US law and requires ingredient labeling in descending order of predominance, net contents, and producer identification. Any therapeutic claim on the label – that it heals chapped skin, reduces inflammation, or treats any condition – converts it to a drug requiring regulatory approval that a small producer cannot practically obtain. Under the Modernization of Cosmetics Regulation Act of 2022, the seller must also substantiate the product's safety, report serious adverse events to FDA, and carry a US contact for such reports on the label; small businesses under about one million dollars in annual cosmetic sales are exempt from registration, listing and manufacturing-practice rules but not from those duties. (2) **Wax quality and residue status:** Wax used in a product applied to skin should come from cappings or other low-residue sources, not old dark brood comb; the beekeeper should know the treatment history of the source colonies and be able to document it. Dark brood comb wax with unknown residue history is not appropriate for a skin-contact product. (3) **Production practice:** Consistent formulation, controlled melting temperatures, clean equipment, and batch records with lot coding allow the producer to trace

any specific batch if a quality issue arises and to recall a batch if needed. (4) **Business and insurance:** General liability insurance is essential before sales begin. State and local regulations for home-based cosmetic manufacturing vary; some jurisdictions require registration or inspection, others have cottage-industry exemptions that apply. The producer should verify applicable rules before the first sale.

- For the beekeeper's own in-hive miticides, the approximate order from highest to lowest is old brood comb wax > propolis > cappings wax > honey, with fresh pollen ranked by what the surrounding crops received. Old brood comb wax has accumulated lipophilic residues over multiple brood cycles and treatment applications – the matrix is long-lived, lipid-rich, and has been in contact with hive-atmosphere residues for years. Propolis is highly lipophilic and absorbs residues readily from the hive environment, though it turns over more quickly than structural comb wax. Cappings wax is chemically similar to brood comb wax but is renewed with each honey cycle and is never used for brood rearing, so it accumulates far lower residue loads. Pollen is the exception to a simple ranking: it arrives carrying whatever was applied to the plants it came from, and residue surveys (Mullin et al. 2010) found pollen carried the widest range of agricultural pesticides and some of the highest concentrations, especially of fungicides, so for field chemicals trapped pollen can outrank cappings wax or even propolis. Honey is a dilute aqueous sugar solution with essentially no capacity to dissolve lipophilic compounds; it consistently shows the lowest miticide and lipophilic pesticide concentrations of any hive product.

17.16 Further Reading

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Mullin, C.A., Frazier, M., Frazier, J.L., et al. "High levels of miticides and agrochemicals in North American apiaries: implications for honey bee health." *PLoS ONE* 5(3): e9754, 2010. The landmark survey of pesticide residues in US hive wax, pollen, and bees; essential reading for any chapter on hive product quality.

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Bogdanov, S. *Bee Product Science* (online reference chapters covering beeswax, propolis, pollen, royal jelly, and venom). Swiss Bee Research Centre. Available at bee-hexagon.net. An accessible synthesis of bee product science by a leading bee-products chemist; individual chapters updated periodically; the royal jelly, propolis, and venom chapters are particularly useful for this domain.

Bankova, V.S., Castro, S.L., & Marcucci, M.C. “Propolis: recent advances in chemistry and plant origin.” *Apidologie* 31(1): 3-15, 2000. The reference for propolis composition, geographic variation, and the diversity of plant sources.

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Borba, R.S., Klyczek, K.K., Mogen, K.L., & Spivak, M. “Seasonal benefits of a natural propolis envelope to honey bee immunity and colony health.” *Journal of Experimental Biology* 218: 3689-3699, 2015. The study showing that colonies with a propolis envelope have lower and more uniform baseline immune-gene expression.

Graham, J.M. (ed.). *The Hive and the Honey Bee.* Dadant & Sons, 2015 edition. The standard comprehensive reference; chapters on hive products, wax biology, and colony products are authoritative starting points.

Crane, E. *Bees and Beekeeping: Science, Practice and World Resources.* Heinemann, 1990. Useful for historical and global context on hive product production, especially royal jelly and venom.

Winston, M.L. *The Biology of the Honey Bee.* Harvard University Press, 1987. The standard biological reference; especially strong on age-related physiology including wax gland development and hypopharyngeal gland function.

US Food and Drug Administration. *Proper Labeling of Honey and Honey Products: Guidance for Industry.* Final Guidance, 2018. Establishes the regulatory framework for honey labeling; relevant to the chapter on product identity and claims; available at fda.gov.

US FDA. *Cosmetic Labeling Guide* (fda.gov) and 21 CFR Part 701 (Cosmetic Labeling). The regulatory basis for ingredient declaration, net contents, and identity requirements for beeswax cosmetics; see also 21 CFR Part 740 (cosmetic product warning statements).

US FDA. *Modernization of Cosmetics Regulation Act of 2022 (MoCRA).* fda.gov/cosmetics. Safety substantiation, serious adverse-event reporting, label contact information, and the small-business exemptions.

University of Florida IFAS Extension. Various publications on bee product handling, pollen trapping, and hive product marketing; extension.ufl.edu. Current extension guidance relevant to southeastern US conditions of temperature and humidity.

Chapter 18. Laws, Regulation, Inspection & Organizations

Covers exam questions Q321-Q331.

18.1 Orientation

Most beekeepers operate for years before regulatory questions become urgent, and then they become urgent all at once: a neighbor complains, an inspector arrives, a disease is suspected, or a commercial opportunity requires shipping bees or honey across a state line. A master beekeeper needs to understand the regulatory framework before any of those moments arrive, because the consequences of getting it wrong can include quarantine, forced destruction of colonies, loss of a market, or personal liability. This chapter covers the framework.

Three ideas organize the rest. First, apiary regulation is fundamentally a state function in the United States, which means requirements differ substantially from state to state and a general text cannot substitute for knowledge of the laws that actually govern the beekeeper's own operation. Second, federal law overlays state law in specific, limited areas — importation of bees, pesticide registration and labeling, and food safety for honey sold in commerce — and those federal requirements set the floor that state requirements build on. Third, the professional organizations that serve beekeepers are themselves part of the regulatory and educational ecosystem: they shape policy, coordinate surveys that drive national response to colony losses, produce the guidance documents that inspectors and beekeepers rely on, and administer the certification programs that define what master-level knowledge means.

The examination probes all three ideas. A candidate who memorizes the name of a federal act but cannot explain what it does, or who knows that AFB is reportable but cannot say why, or who can name organizations but cannot distinguish what each contributes, will struggle. The exam is built on mechanism and consequence, not on lists. That is the standard this chapter is written to.

18.2 Apiary Law Is State Law

The authority to regulate apiaries in the United States rests primarily with the individual states, not with the federal government. In most states that have enacted an apiary law, its administration rests with the state department of agriculture, which writes the accompanying regulations and operates an apiary inspection program - but not in all: the Texas Apiary Inspection Service, for example, is part of Texas A&M AgriLife. Because each state acts independently, requirements differ substantially in what they mandate, how they are enforced, and what consequences follow noncompliance.

The common elements that appear in most state apiary acts are worth understanding structurally even though the details vary. Registration is the usual starting point: in a 2021 Apiary Inspectors of America survey, about 58 percent of responding states required beekeepers to register, typically by apiary location, providing the address or GPS coordinates, the number of colonies at that location, and the beekeeper's contact information. Registration serves two purposes — it creates a record the

department can use to notify beekeepers of disease outbreaks or chemical applications in their area, and it tells the inspector where colonies are. The inspector's legal authority to enter and inspect comes from the state apiary statute itself, not from the beekeeper's registration. Without registration, the inspector has no paperwork establishing that hives exist at a given location, which complicates both routine inspection and emergency response.

Inspection authority follows registration. State apiary inspectors are authorized to enter the premises where registered hives are kept, open and examine colonies, and collect samples for laboratory analysis. This authority is not discretionary from the beekeeper's side: a registered beekeeper must provide access and cooperate with the inspection. The inspector examines adult bees and brood for signs of disease, assesses equipment condition, confirms that hive marking requirements are met where they exist, and issues a certificate of inspection recording the findings. The beekeeper receives a copy; the state keeps one for its records.

What distinguishes state apiary law from ordinary agricultural regulation is the authority to order quarantine or destruction. Because certain diseases — American foulbrood above all — can spread to any colony within flight range and because spores persist in equipment for decades, states treat diseased colonies as a community problem, not a private one. An inspector who confirms a notifiable disease can issue a quarantine order restricting movement of hives and equipment from the affected location, and in the case of American foulbrood can order destruction of infected colonies and equipment by burning. Some states authorize this without compensation; others have indemnity provisions. The legal basis for these orders is the state's police power to protect agricultural resources, which courts have consistently upheld.

The practical implication for any beekeeper is simple: know your state's apiary act and regulations, not a general description of what apiary acts typically contain. The variation among states is real, and a requirement that does not exist in one state may be legally mandatory in the next.

18.3 What Apiary Inspectors Do and Do Not Do

A state apiary inspector is a credentialed employee of the state's apiary regulatory agency (usually the department of agriculture), not a pest control officer, a law enforcement officer, or an extension educator. The inspector's job is to assess the health of colonies, enforce the provisions of the state apiary act, and facilitate communication between the beekeeper and the department.

A routine inspection covers several distinct things. The inspector examines brood combs visually for the characteristic signs of American foulbrood (ropiness, sunken and perforated cappings, brown discoloration, the distinctive odor), European foulbrood (yellowish or brown larvae in twisted positions, souring smell), chalkbrood (mummified larvae, chalky white or black), and sacbrood (larvae in fluid-filled sacs). The inspector examines the adult bee population for signs of Varroa infestation, Nosema, and in some jurisdictions tracheal mite. The queen's condition is noted — whether she is present, what her laying pattern looks like, and whether the colony appears headed adequately. Equipment is assessed for condition and, where state law requires it, for owner identification marking. Some states require that

hives bear the owner's identification number stamped or branded on the box; this lets any inspector who encounters a hive know where to direct findings.

What the inspector does not do is provide free consulting on swarm control, honey extraction, or queen rearing. The inspector's authority is regulatory; advisory services are the province of extension programs and organizations. The distinction matters because a beekeeper who treats an inspector visit as a training session is misreading the relationship, and an inspector who makes informal promises about regulatory outcomes is speaking outside their authority. The beekeeper's obligation is to cooperate with the inspection, accept the findings, and comply with any lawful order.

Hive marking requirements illustrate how state law can reach into seemingly mundane practices. Where marking is required, unmarked hives can be treated as abandoned or as evidence of regulatory noncompliance. A beekeeper purchasing used equipment should check whether the previous owner's marking creates any complication — for example, whether transferring unmarked hives purchased out of state satisfies the destination state's requirements.

18.4 Notifiable Diseases and the Duty to Report

American foulbrood is the paradigm case of a notifiable bee disease, and the rationale for its regulatory treatment explains the whole framework.

Paenibacillus larvae spores are extraordinarily durable: documented persistence in old comb and equipment runs to thirty-five years and more, with some experimental results suggesting much longer survival under dry conditions. A single infected colony can spread the disease through robbing and drifting to every apiary within a several-kilometer radius, and infected equipment stored in a barn continues to harbor infectious spores indefinitely. These characteristics mean that one beekeeper's failure to act affects every other beekeeper in the neighborhood. The disease is therefore defined as a community problem, and the law creates corresponding community obligations.

The primary obligation is reporting. Where American foulbrood is listed as a notifiable condition — and it is in most states with an apiary program — a beekeeper who suspects or confirms the disease is legally required to report the finding to the state apiary inspector. Failure to report is itself a violation of state apiary law, separate from whatever harm the disease may cause. The rationale is straightforward: the inspector cannot confirm the diagnosis and order a response without knowing the disease is present, and delayed notification allows the infection to spread.

Once the inspector confirms the diagnosis, the authority to act follows. Quarantine orders restricting movement of equipment from the infected location are standard. For colonies positive for American foulbrood, the overwhelming consensus in regulatory practice is that infected colonies and equipment must be burned, because burning is the only reliable way available to most beekeepers to destroy spores in frames, beeswax, and propolis (gamma irradiation is an alternative where a facility exists, and some states allow scraped boxes to be scorched or paraffin-dipped). Antibiotics suppress the vegetative stage of the bacterium but do not kill spores, which is why the historical practice of antibiotic treatment to suppress clinical signs has always been regarded as a management measure rather than a cure, and why burning remains the standard in jurisdictions where inspectors have authority to order it.

The shift to veterinary oversight of antibiotics beginning in January 2017 sharpened the logic of laboratory confirmation. Under the Veterinary Feed Directive framework that took effect on that date, oxytetracycline, tylosin, and lincomycin — the three antibiotics approved for use in honey bees — require either a Veterinary Feed Directive from a licensed veterinarian for in-feed formulations or a prescription for water-soluble ones. Over-the-counter purchase of these drugs for prophylactic or therapeutic use in bees is no longer lawful. To write a VFD or prescription, a veterinarian needs a diagnosis. That means the era of treating any dying brood on suspicion with a powder duster of antibiotic, without knowing whether the cause was American foulbrood, European foulbrood, or something else entirely, is legally closed. A beekeeper now needs a veterinarian's diagnosis, ideally backed by a laboratory result, to support antibiotic use, which in turn reinforces the argument for reporting to the inspector and allowing the inspector to submit samples through the official diagnostic chain rather than sending a comb fragment to a private lab as a first step.

European foulbrood, small hive beetle, and Varroa appear on the notifiable lists of some states but not others. A master beekeeper in a given state must know which diseases are notifiable there.

18.5 Moving Bees: Interstate Movement and What It Requires

No area of apiary law produces more enforcement problems for commercial and serious sideline beekeepers than the movement of bees across state lines. The consequences of noncompliance range from quarantine at the destination state line to outright refusal of entry and, in some states, destruction of the colonies.

The basic requirement is a certificate of inspection issued by the origin state's apiary inspector — or in some states by an extension specialist or licensed apiarist — after an inspection establishing that the colonies being moved are free of American foulbrood and European foulbrood, and often certifying findings related to Varroa levels or the absence of Africanized bee characteristics. The certificate specifies the number of colonies, the location from which they are moving, the destination, and the validity period. That validity period is meaningful: a certificate issued for an inspection that was done weeks before the actual movement may have expired by the time the truck arrives at the state line, and an expired certificate is no certificate at all.

Before any move, the beekeeper should contact the destination state's apiary regulatory authority — typically the state department of agriculture — and confirm the current entry requirements. Requirements change. What was acceptable last season may not be sufficient this season: a state may have added a requirement related to Africanized bee documentation, or lowered the mite level it will accept, or changed the form a certificate must take. Calling ahead also establishes the beekeeper's good faith, which matters if there is a problem at the border.

Entry requirements commonly address several categories. The most universal is the AFB and EFB certificate. Some states additionally require documentation of Varroa levels. In areas where Africanized honey bee populations are present or suspected — parts of the Gulf coastal region and southwestern portions of the country — states may require certification that colonies originate from documented European stock or have been tested and found negative for Africanized characteristics. Some states

require a permit or advance notification that a shipment is coming; others require registration of the colonies in the destination state for the period of the stay. Pollination contractors routinely have colonies under registration in multiple states simultaneously.

The reason strict compliance matters beyond inconvenience is consequence. Entry requirements are set and enforced by the destination state, and a load that arrives without valid certification can be quarantined, turned back or, in some states, destroyed at the owner's expense. The diseases and pests the certificate addresses are also the ones that make an uncertified load a hazard to every beekeeper in the receiving area.

The movement of equipment, not just live bees, is also regulated. Used comb and wooden equipment that has housed bees can carry AFB spores, small hive beetle eggs, and other problems. Several states restrict or prohibit the movement of used equipment without inspection or treatment. A beekeeper bringing empty supers home from a pollination contract in a neighboring state should check whether the equipment needs to be declared and inspected on return.

18.6 Federal Jurisdiction: USDA APHIS and Importation Controls

While day-to-day apiary regulation is a state function, the federal government exercises exclusive authority over one domain that shapes the disease environment of every apiary in the country: the importation of bees and bee products from other nations.

The Honey Bee Act of 1922, codified at 7 U.S.C. 281-286, is the foundational statute. Enacted in response to Isle of Wight disease, the adult bee losses then sweeping British apiaries and attributed to the newly described tracheal mite (*Acarapis woodi*), the act was originally aimed at keeping that mite out of the country. It authorized the Secretary of Agriculture to prohibit or restrict the importation of honey bees into the United States; as amended, the act covers all life stages, germ plasm and semen of the genus *Apis*. APHIS's implementing rules (7 CFR part 322), which also rest on the Plant Protection Act, additionally restrict certain bee products and used equipment. The administration of this authority rests with USDA's Animal and Plant Health Inspection Service (APHIS). The act has been amended several times to reflect changing disease threats and diplomatic relationships, and APHIS maintains a list of countries from which importation is permitted under various conditions, as well as countries from which importation is prohibited.

The central prohibition that has shaped modern American beekeeping is the restriction on the importation of adult honey bees. The restriction outlived its original target and has been kept and tightened as new threats appeared: because Varroa destructor was present throughout Europe and much of the rest of the world, and because even more dangerous parasites — particularly *Tropilaelaps mercedesae* and related species — exist in Asian bee populations, the importation of adult bees from most countries is prohibited or tightly controlled. The concern is not theoretical: *Tropilaelaps* is regarded by USDA APHIS and the international beekeeping research community as the most significant new parasite threat to *Apis mellifera* beekeeping, with potential to cause colony losses faster than Varroa because of its shorter reproductive cycle and its preference for brood over adult bees. A 2026 report documented interception of an *Apis dorsata* swarm carrying *T. mercedesae* on a cargo vessel inbound to

the United States, illustrating both the reality of the threat and the functioning of the interception system.

The act did not prevent the arrival of either tracheal mite (*Acarapis woodi*, first detected in the United States in 1984) or Varroa (*Varroa destructor*, 1987). Both became established despite import restrictions that had been in force since 1922 and were tightened in 1962 and 1976, most likely through illegal or unregulated introductions. The act nonetheless remains the legal mechanism by which APHIS attempts to prevent the introduction of additional exotic parasites and pathogens. The practical consequence for any beekeeper is that packages, queens, and germplasm imported from another country must originate from a country and source approved by APHIS under current regulations. Purchasing queens from a foreign seller who ships them without APHIS authorization is not simply a customs irregularity; it is a violation of federal importation law.

USDA AMS (Agricultural Marketing Service) operates a separate, voluntary honey grading program. Producers who want to display the USDA Grade A shield on their honey must request grading and meet the standards the AMS administers. The program is not required for interstate honey sales, but the shield is valuable in certain commercial channels, and a master beekeeper should know that it exists and is voluntary, and that its administration is distinct from the food safety and labeling oversight that the FDA exercises.

18.7 FIFRA, Pesticide Incidents, and Enforcement

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) is the statute that governs pesticide registration, labeling, and use in the United States. The Environmental Protection Agency (EPA) administers FIFRA at the federal level, reviewing data, setting conditions, and issuing registrations for pesticide products. The pesticide label is federal law under FIFRA — not a suggestion, not a recommendation — and use of a pesticide in a manner inconsistent with the label, including application to crops in a way that the label does not authorize during bloom, is a FIFRA violation.

Day-to-day enforcement of FIFRA on the ground is the responsibility of state lead agencies. In most states the lead agency is the state department of agriculture, which licenses pesticide applicators, receives pesticide incident reports, and investigates alleged misuse. This delegation of enforcement to the states is the reason that a beekeeper who suspects that a pesticide application killed or damaged their colonies should contact the state lead agency — typically the same department of agriculture that houses the apiary inspection program — and not the EPA directly.

The state apiary inspector is also a critical contact in a pesticide incident because the inspector can document hive condition, collect samples under a defensible chain of custody, and interface with the pesticide program within the same agency. Documentation and chain of custody matter enormously in these cases: pesticide residues degrade, and a sample collected days after the incident and sent without documentation to a private laboratory may be insufficient to support an enforcement determination. The correct procedure is to preserve samples by freezing them promptly — dead bees, comb, and where possible some of the adult bees from the vicinity — document the incident in photographs with

timestamps and GPS coordinates, and then contact the state lead agency and follow their instructions for formal sample submission.

The beekeeper does not initiate law enforcement action directly. FIFRA investigations are civil enforcement matters, not criminal cases in most circumstances, and they proceed through the state regulatory process. A beekeeper who expects the investigation to confirm that a neighbor violated the label will be better served by having proper samples and documentation than by having strong opinions about what happened.

18.8 Honey Sales, Cottage Food Laws, and FDA Oversight

A beekeeper who sells honey at the end of a farm lane or at a local farmers market under a state's cottage food exemption is operating under a very different legal framework than one who ships honey to a regional retailer or sells online to buyers in other states. Understanding the distinction is increasingly important as beekeeper operations grow.

Cottage food laws are state statutes — not federal law — that permit certain low-risk foods to be produced in a residential kitchen or small facility and sold directly to consumers without the licensing, facility inspection, and food safety plan requirements that apply to commercial food processors. Honey is among the products most commonly permitted under cottage food provisions, partly because it is chemically stable and self-preserving, and partly because state legislatures have responded to beekeeper advocacy. Some states have separate statutory provisions specific to honey and beeswax that stand apart from the general cottage food statute and may be more permissive.

Before selling, a beekeeper must determine several things that vary by state and municipality. First, whether the cottage food or honey-specific provision actually applies to their operation at their current scale: most cottage food laws cap annual gross sales at a stated dollar amount, and operations that exceed that cap are no longer exempt from commercial food processing licensure requirements, no matter how the product is sold. Second, which sales channels the exemption covers: virtually all cottage food provisions limit sales to direct-to-consumer transactions, meaning in-person sales at the farm, at a farmers market, or at a similar venue where the producer and consumer interact directly. Cottage food exemptions typically do not cover sales to a retailer for resale or shipment of product to a buyer in another state, and many do not cover internet sales, although some states now allow in-state online or mail-order sales. Third, what labeling the state requires in addition to whatever federal labeling applies. Many states require a statement on the label indicating that the product was produced in a cottage food operation not subject to state food safety regulations. Some states require an advisory statement about honey and infants.

When a beekeeper expands beyond what the cottage food or honey-specific exemption covers — whether by exceeding the sales cap, adding a wholesale account, shipping to customers in other states, or selling through an internet platform — the regulatory picture changes materially. Wholesale sales and interstate sales generally require production in a facility that has been inspected and licensed by the state, or in some cases that has passed a food safety audit. These sales also bring the producer under

the full federal labeling requirements of the Federal Food, Drug, and Cosmetic Act and, depending on scale and structure, under the Food Safety Modernization Act.

FDA's food safety jurisdiction over honey sold as food has several practical implications. The FD&C Act's misbranding provisions are the primary enforcement tool: a honey product labeled as pure honey that contains added sweeteners, or a product labeled with a floral variety that is not supported by any information about what the bees actually foraged, violates the misbranding provisions. FDA issued a final guidance document in 2018 titled "Proper Labeling of Honey and Honey Products" that clarifies these requirements. The statement of identity for pure honey is simply "honey" — no other descriptor is required or necessarily appropriate. A product that contains honey and another sweetener is not honey; it requires a common or usual name describing what it actually is, such as "blend of honey and corn syrup," with an ingredient statement in descending order of predominance by weight. A floral source may be named on the label, but only if the producer has information — records of where colonies were placed, what was in bloom, what the color and flavor indicate — supporting that the named plant was the chief floral source. The guidance document is styled as containing nonbinding recommendations, but the underlying misbranding provisions of the FD&C Act are binding federal law; the guidance interprets how those provisions apply to honey.

FSMA, enacted in 2011 and implemented in regulations phased in through the mid-2010s, reaches honey mainly through the Preventive Controls for Human Food rule (21 CFR 117), which applies to food facilities that must register with FDA. Under FDA's farm definition, a beekeeper who extracts and bottles only his or her own honey is generally treated as a farm, and farms are not subject to that rule; an operation that packs or blends honey bought from others, or processes beyond farm activities, may have to register, and registered facilities that qualify as very small businesses may be eligible for modified requirements. The framework is not simple, and its application to a given operation depends on the specifics of what that operation does and how it sells. What a master beekeeper needs to know is that FSMA exists, that neither farm status nor an exemption is automatic, and that an operation growing toward commercial scale should get specific guidance on whether and how FSMA applies before committing to a market channel that turns out to require a food safety plan the operation cannot yet support.

18.9 Municipal Ordinances and Neighbor Relations

Below the state level, many municipalities and counties have adopted beekeeping ordinances that regulate where hives may be kept and under what conditions. The content of these ordinances varies widely — some are single-sentence mentions in a livestock or nuisance code, others are detailed regulations running several pages — but common elements appear repeatedly.

Colony density is the most common subject: ordinances typically establish a maximum number of hives per lot, sometimes expressed as a ratio to lot size. Setback requirements specify the minimum distance between hive entrances and property lines, residential structures, and public walkways. Flyway barrier requirements mandate that beekeepers erect a fence, hedge, or wall that forces departing bees to climb above head height before crossing a property line, which reduces the incidence of bee-human contact with neighbors going about their business at ground level. Water source requirements mandate that the

beekeeper provide fresh water at the apiary to reduce the likelihood that bees will establish at a neighbor's pool or ornamental feature. Some ordinances require municipal registration separate from any state registration requirement.

A complication that varies by state is the relationship between state law and local authority over agricultural activities. Some states have enacted right-to-farm statutes or provisions that limit municipal authority to restrict agricultural activity, including beekeeping. Whether such provisions preempt a local beekeeping ordinance depends on how the statute is written and how courts in that state have interpreted it. The application of right-to-farm provisions to residential-zone beekeeping is not uniform and is in active legal development in some states. A beekeeper relying on a right-to-farm argument to override a local ordinance should have that argument reviewed by a local attorney before acting on it.

Homeowners association covenants operate entirely separately from public law. An HOA covenant prohibiting livestock or animals beyond household pets may effectively prohibit beekeeping regardless of what the municipal code permits, because HOA covenants are private contracts enforced through civil litigation, not public regulatory processes. A beekeeper subject to an HOA agreement who wishes to keep bees should review the covenant language before establishing an apiary, because discovering the violation after the apiary is established is significantly more disruptive than checking beforehand.

Master beekeepers are often called on to advise city or county governments in the process of drafting beekeeping ordinances. The value a master beekeeper brings is knowledge of what problems ordinances are actually designed to address — defensiveness, swarms, water competition — and what measures actually address those problems versus measures that sound plausible but accomplish little. The best ordinances are those that focus on management outcomes (gentle stock, swarm control, water provision, flyway barriers) rather than trying to eliminate beekeeping entirely or imposing detailed equipment requirements that the jurisdiction cannot meaningfully enforce.

18.10 Liability When a Neighbor Is Stung

A neighbor who is stung by bees from a nearby apiary may have a legal claim against the beekeeper, and a master beekeeper needs to understand the framework even though specific legal questions should go to a qualified attorney. The two primary theories under which a claim might be made are negligence and private nuisance.

Negligence asks whether the beekeeper exercised reasonable care in siting and managing the colonies. The relevant questions are whether the beekeeper followed applicable ordinances and regulations, whether the site was chosen with appropriate attention to proximity to neighbors and foot traffic, whether the stock was reasonably gentle for the location, whether defensive behavior was promptly addressed, and whether the beekeeper maintained the operation in a way that a reasonable beekeeper in similar circumstances would recognize as appropriate. Compliance with local ordinances is relevant to this analysis but is not automatically sufficient: a beekeeper can comply with every ordinance and still be found negligent if the particular circumstances called for additional precautions that a reasonable person would have taken.

Private nuisance asks whether the operation substantially and unreasonably interferes with the neighbor's use and enjoyment of their property. A single sting by a bee that happened to be foraging is unlikely to constitute a nuisance; repeated stinging incidents, a defensive colony that prevents the neighbor from using their yard, or bees clustering on a neighbor's property during a swarm event are more likely to support a nuisance claim.

Practical measures that reduce exposure to both theories include: keeping the most gentle stock available and requeening any colony that shows defensive behavior promptly, without waiting to see whether the behavior improves; providing a reliable on-site water source to minimize bees' use of a neighbor's water; using flyway barriers to raise flight paths above the level where humans are likely to encounter bees; siting hives away from property lines, driveways, shared fences, and outdoor living areas; practicing active swarm control so that swarms do not issue from the apiary and arrive uninvited in the neighbor's yard or house; maintaining good neighbor relations through communication and the occasional jar of honey; and carrying appropriate liability insurance. An insurance policy does not prevent a lawsuit, but it means that the beekeeper has resources to respond to one and that the neighbor's attorney knows there is a party capable of paying a judgment, which often changes the calculus of whether litigation is pursued.

18.11 Beekeeping Organizations and Why They Matter

A master beekeeper is expected to know not just what organizations exist but what each one does, because the question of where authoritative and current information comes from is itself a master-level competency.

At the national level, the American Beekeeping Federation (ABF) and the American Honey Producers Association (AHPA) are the primary trade organizations representing commercial and serious sideline beekeepers on policy matters before Congress, USDA, EPA, and FDA. They engage on issues including pesticide registration, honey imports, crop insurance, and research funding. Their conferences and publications connect members with current research and regulatory developments.

The Apiary Inspectors of America (AIA) is the organization of state apiary inspectors — the professional association for the people who actually enforce state apiary law. AIA coordinates regulatory standards across states, provides professional development for inspectors, and contributes to the national colony loss surveys that are conducted annually. A beekeeper with a dispute or a question about state regulatory requirements benefits from understanding that AIA is the channel through which state programs coordinate nationally, even though the beekeeper's direct contact point is always the state agency.

The Bee Informed Partnership (BIP), a multi-institutional effort linking university apiculture programs and practicing beekeepers, ran the annual colony loss and management surveys that produced the national loss statistics for more than a decade. The survey now continues as the U.S. Beekeeping Survey, led by Auburn University with Oregon State University and the Apiary Inspectors of America; its most recent figures — 55.6% losses in 2024-25, falling to a preliminary 39.9% in 2025-26 — come from beekeepers managing roughly 13% of the nation's managed honey-producing colonies. BIP also ran

technical transfer teams that placed trained apiculture technicians with commercial operations to identify management factors associated with better or worse colony outcomes. BIP restricted its activities in fall 2023, but its published survey data and technical transfer findings remain a valuable historical evidence base on what management practices are associated with better colony survival.

The Honey Bee Health Coalition (HBHC) is a multi-stakeholder group that convenes beekeepers, researchers, commodity groups, agricultural industry representatives, and government agencies around shared goals. Its most widely used product for working beekeepers is the *Tools for Varroa Management* guide, now in its 9th edition released June 22, 2026, which synthesizes current evidence on Varroa monitoring and treatment options into a practical decision-support format. The Coalition also works on pesticide exposure, habitat, and nutrition, producing guidance documents and facilitating research coordination.

The Eastern Apicultural Society (EAS) and Western Apicultural Society (WAS) are regional organizations that provide annual conferences, short courses, and connecting beekeepers with researchers and with each other. EAS's annual meeting is the principal gathering for beekeepers and researchers in the eastern portion of the country. EAS also administers the most thoroughly documented master beekeeper certification program in the United States. WAS serves roughly the western states with a comparable mission.

State and local beekeeping associations supply the kind of region-specific knowledge that national organizations cannot replicate. A new beekeeper asking when the tulip poplar flow peaks in the Piedmont, or which forage species has expanded or contracted in the last decade in the coastal plain, gets an answer from the local association that no national guide can provide. These associations also serve as the primary social network connecting new beekeepers with mentors and connecting all beekeepers with the state apiary inspection service through programs and referrals.

University Cooperative Extension apiculture programs are distinct from, but work alongside, the organizational structure. Extension programs at land-grant universities in the southeastern states produce region-specific publications on bee management, disease control, and the local regulatory framework. They conduct applied research, train beginning and intermediate beekeepers, and in some cases house the state's master beekeeper certification program within the extension framework rather than within a regional society. Publications from these programs are among the most reliably current sources on state-specific requirements.

18.12 Master Beekeeper Certification Programs

Master beekeeper certification exists in multiple forms: some programs are administered by regional apicultural societies, others by state beekeeping associations in partnership with university extension programs. What these programs share is a commitment to assessing mastery — the ability to work effectively, communicate accurately, and reason through novel situations — rather than simply testing whether a candidate can answer factual recall questions correctly.

The EAS Master Beekeeper program is the most thoroughly documented and the one most directly relevant to the certification examination this guide accompanies. EAS requires that a candidate have a

minimum of five years of serious beekeeping experience and be an EAS member at the time of the examination. The program consists of four components: a written examination, a laboratory examination, an oral examination, and a field examination. All four components must be passed within five consecutive years of the date on which the candidate first attempts any component. Individual components that are not passed may be retaken within that window; there is no requirement to restart the entire process after a failed component, but the five-year clock does not reset.

The written component tests the breadth of knowledge that an experienced beekeeper should have about bee biology, diseases, management, genetics, products, and — as this chapter covers — regulatory and organizational context. The laboratory component requires the candidate to identify disease signs, bee parasites and pathogens, equipment, and bee morphology from specimens and samples. The field component involves inspecting an unfamiliar colony provided by the examiners, working the bees, and reporting findings correctly. The oral component requires the candidate to communicate their knowledge accurately and honestly to both beekeepers and members of the general public, including being able to say clearly where their certainty ends and where they would seek additional information or refer the question to a specialist.

The field and oral components exist for a reason that is central to what the master designation means. A candidate who has mastered the textbook but cannot work an unfamiliar colony calmly, cannot diagnose brood disease from live frames under examination conditions, or cannot explain the AFB life cycle to a nervous new beekeeper in language that person can act on, has not met the standard. The role of a master beekeeper is substantially a teaching and advising role — hence the principle that the program evaluates mastery, not competency. Competency means doing the job adequately. Mastery means being able to explain what you are doing and why, to evaluate your own uncertainty honestly, and to serve as a resource for others.

State-level tiered programs follow a similar logic but typically extend the progression further. A tiered program might include a certified level assessing basic knowledge, a journeyman level requiring more advanced examination and some evidence of teaching or community contribution, a master level requiring all of the above plus substantial public service hours, and a master craftsman level requiring further demonstrated contribution to the craft and the community. The public service requirement at the upper tiers reflects the same reasoning: beekeeper education and community contribution are not optional extras for a master-level beekeeper; they are the primary ways that advanced knowledge reaches the people who need it.

The inclusion of regulatory knowledge in master beekeeper certification is sometimes misunderstood as tangential to “real” beekeeping. The misunderstanding gets the relationship backward. A beekeeper who cannot advise a neighbor on whether and how to register their hives, who does not know whether a suspect colony must be reported, who moves bees across state lines without proper documentation, or who sells honey commercially without understanding the applicable food safety framework is not serving the community function that the master designation implies. Regulatory literacy is part of the job.

18.13 Numbers to Know Cold

Figure	Value	Why it is that value
Honey Bee Act of 1922 statutory citation	7 U.S.C. 281-286	Federal importation restriction authority; enacted originally to keep out the tracheal mite (Isle of Wight disease), now the basis of all bee import control
Date veterinary oversight of bee antibiotics became mandatory	January 1, 2017	VFD framework took effect; OTC purchase for prophylactic use became unlawful
Antibiotics requiring veterinary oversight in bees	Oxytetracycline, tylosin, lincomycin	The three antibiotics FDA-approved for use in honey bees
FDA honey labeling final guidance	2018	"Proper Labeling of Honey and Honey Products" — interprets FD&C Act misbranding provisions as applied to honey
HBHC *Tools for Varroa Management* current edition	9th edition, June 22, 2026	Most current synthesis of Varroa monitoring and treatment evidence; supersedes 8th edition (August 2022)
EAS master beekeeper minimum experience	5 years	Program requires five years of serious beekeeping before sitting the examination
EAS master beekeeper exam components	4 (written, laboratory, oral, field)	Each must be passed; all four must be completed within five consecutive years
EAS five-year completion window	5 consecutive years from first attempt	Individual components may be retaken within this window
Federal statute governing pesticide registration and labeling	FIFRA (Federal Insecticide, Fungicide, and Rodenticide Act)	EPA administers nationally; state lead agencies enforce on the ground
FIFRA ground-level enforcement entity	State lead agency (usually state dept. of agriculture)	Where pesticide incident reports go; issues pesticide applicator licenses
USDA agency regulating bee imports	APHIS (Animal and Plant Health Inspection Service)	Administers Honey Bee Act; maintains prohibited and approved country lists
USDA agency administering voluntary honey grading	AMS (Agricultural Marketing Service)	USDA Grade A shield is voluntary, not required for commerce
Food Safety Modernization Act (FSMA) enacted	2011	Preventive Controls for Human Food rule applies to registered food facilities (e.g., packers of others' honey); a beekeeper bottling only his or her own honey is generally a farm and not subject to it
US colony loss 2024-25	55.6%	Highest recorded annual loss; U.S. Beekeeping Survey (Auburn-led); roughly three times the 15-20% beekeepers call acceptable

Figure	Value	Why it is that value
US colony loss 2025-26	39.9% (preliminary)	Fall from record but still roughly double the 15-20% beekeepers describe as acceptable
Amitraz resistance marker in Varroa (2026)	Y215H mutation in the Octβ2R gene found in all 39 mites screened from the sampled operations (Lamas et al. 2026)	Compared with 66% (82/125) in an earlier regional U.S. survey; all operations sampled had relied mainly on amitraz
AFB spore environmental persistence	Decades; documented to 35+ years	Basis for treating AFB as community problem requiring mandatory reporting and burning

18.14 Common Misconceptions

Misconception: Apiary laws are set by the federal government, so requirements are the same across all states. **Correction:** Apiary regulation is a state function. Each state enacts its own apiary act and regulations, usually administered by its department of agriculture. Requirements for registration, inspection, notifiable diseases, hive marking, and movement certification differ substantially among states. A beekeeper who moves from one state to another and assumes the rules are the same will find, at some point, that they are wrong.

Misconception: Because American foulbrood cannot be cured by antibiotics anyway, there is no reason to notify the state — just burn the equipment and move on. **Correction:** Reporting is a legal obligation in states where AFB is notifiable, separate from whatever the beekeeper does about their own colonies. The inspector's role is to confirm the diagnosis, assess the risk of spread to neighboring apiaries, and ensure that quarantine and disposal are handled in a way that actually contains the disease. An uninspected fire that leaves contaminated ashes or equipment fragments does not necessarily contain the spores. Independent disposal may also violate the terms of the quarantine order that the inspector would have issued.

Misconception: The veterinary oversight requirement for bee antibiotics means beekeepers cannot treat foulbrood at all. **Correction:** Antibiotics remain available for use in honey bees; what changed is that they now require a Veterinary Feed Directive or prescription from a licensed veterinarian with an established veterinarian-client-patient relationship. The practical effect is that a beekeeper must have a relationship with a veterinarian, the veterinarian must be able to support the prescription with a diagnosis, and routine prophylactic treatment without evidence of disease is no longer lawful. Getting a laboratory diagnosis and then working with a veterinarian is the correct process.

Misconception: A cottage food exemption allows a beekeeper to sell honey through any channel, as long as the total sales volume stays below the state's cap. **Correction:** Most cottage food exemptions restrict not just the volume of sales but the sales channel. Direct-to-consumer, in-person sales are the standard permitted channel. Internet sales, wholesale to retailers, and shipments to buyers in other states are generally not covered by a cottage food exemption, regardless of the sales volume involved.

Misconception: Selling honey across state lines requires no additional compliance as long as the honey is properly labeled. **Correction:** Interstate honey sales generally require production in an inspected or licensed facility, not just proper labeling. Cottage food exemptions are state law provisions that govern intrastate direct sales; they do not provide exemption from the facility licensing requirements that apply when honey enters interstate commerce. Labeling requirements also apply independently of facility licensing requirements.

Misconception: The pesticide to report to is the EPA, because pesticides are a federal program. **Correction:** FIFRA enforcement on the ground runs through state lead agencies — typically the state department of agriculture — not through the EPA directly. A beekeeper with a pesticide kill incident should contact the state lead agency and the state apiary inspector, not the EPA regional office, as the first step. The EPA may receive information as part of an investigation, but the state agency is where the complaint is filed and the investigation initiated.

Misconception: The Honey Bee Act of 1922 successfully prevented the entry of Varroa and tracheal mite into the United States. **Correction:** It did not. Both parasites entered the country and became established despite existing import restrictions. The act remains the legal basis for current importation controls, and it is why a beekeeper cannot freely import queens from a country not on APHIS's approved list, but it is not evidence that quarantine is foolproof. The value of the control is in reducing and delaying introductions, not in guaranteeing exclusion.

Misconception: Master beekeeper certification programs test written knowledge only, because practical beekeeping skill varies too much by region to be examined consistently. **Correction:** Established programs include written, laboratory, oral, and field examination components, for a reason. The practical and oral components are designed exactly to assess what varies and cannot be inferred from written answers alone: the ability to work a colony under examination conditions, diagnose brood disease from live frames, and communicate findings clearly to a range of audiences. Someone who passes only a written test has not demonstrated that they can actually do the job.

Misconception: Right-to-farm statutes protect beekeepers from all local ordinance restrictions. **Correction:** Right-to-farm provisions vary in how they are written and how courts in a given state have interpreted them. Whether a right-to-farm statute preempts a municipal ordinance regulating residential-zone beekeeping is a state-specific legal question that is not settled uniformly. Homeowners association covenants are private contracts not affected by public right-to-farm statutes at all and may prohibit beekeeping regardless of what public law permits.

Misconception: Selling honey with a floral variety name, such as "wildflower honey," is always acceptable as long as the honey tastes like it came from diverse sources. **Correction:** FDA's 2018 honey labeling guidance states that a floral source may be named on the label only if there is information supporting that the named plant is the chief floral source of the honey. Taste and aroma are not themselves sufficient documentation. A beekeeper naming a variety should be able to point to records of where colonies were kept, what was in bloom during the flow, and ideally pollen analysis or other supporting evidence.

Misconception: Local beekeeping ordinances typically specify which equipment brands or frame dimensions must be used so that inspectors can open any hive with standard tools. **Correction:** Local ordinances typically address siting, colony density, setbacks, flyway barriers, water provision, and sometimes registration. Equipment specification is not a standard element of municipal beekeeping ordinances and would be difficult to justify legally. Inspection protocol is a state-level matter and is governed by the state apiary act, not municipal code.

18.15 Self-Check Questions

- Explain why apiary regulation in the United States is primarily a state rather than a federal function, and describe two consequences of that structure for a beekeeper who moves frequently or who operates in multiple states.
- A beekeeper confirms, by laboratory diagnosis, that one colony in their apiary has American foulbrood. Walk through their legal obligations from the moment of confirmation, including who they must notify, what they must do with the equipment, and why burning is required rather than antibiotic treatment.
- Distinguish between what a state apiary inspector is authorized to do under a typical state apiary act and what the inspector is not authorized to do. What happens if a beekeeper refuses to provide the inspector access to registered hives?
- Describe the complete process a beekeeper should follow before moving fifty colonies from one state to another for blueberry pollination. What documents should they have in hand when the truck reaches the destination state line?
- A sideline beekeeper currently sells at two local farmers markets under a state cottage food exemption and wants to expand by adding a wholesale account with a regional grocery chain and setting up an online store. Explain what regulatory changes this expansion triggers and what the beekeeper needs to determine before proceeding.
- The Honey Bee Act of 1922 is the primary federal statute controlling bee importation, yet both tracheal mite and Varroa became established in the United States despite its existence. Does this mean the act is ineffective and should be repealed? Explain your reasoning.
- A neighbor calls to complain that bees from your apiary have stung her twice while she was gardening. Explain the legal theories under which she could bring a claim against you, and list six specific management or siting measures that reduce your exposure under each theory.
- A beekeeper discovers dead colonies in front of their hives and suspects that a nearby farm applied a pesticide to a crop while it was in bloom. Describe the correct sequence of actions, explaining why each step matters and why acting out of sequence can undermine the investigation.
- What four organizations are explicitly named or implied in the annual US colony loss survey reports, and what distinct role does each play in the production or distribution of that survey?

- Explain the design rationale for including a field examination and an oral examination in a master beekeeper certification program. Why are these components not redundant with the written examination?

- A small honey producer's state has a right-to-farm statute, and the municipality where they live has adopted an ordinance limiting backyard beekeeping to two hives. The beekeeper has five hives. The beekeeper's neighbor also happens to be subject to an HOA covenant that prohibits "livestock and farm animals" on residential lots. Analyze the three separate legal frameworks that may apply to this situation, noting where the outcome is clear and where it is genuinely uncertain.

- Why did the shift of antibiotics for honey bees from over-the-counter to veterinary oversight (effective January 2017) push the field toward laboratory confirmation of American foulbrood rather than treatment on suspicion? What is the connection between this regulatory change and the rationale for reporting to a state apiary inspector?

18.16 Self-Check Answers

- Apiary law is a state function because the states retain authority over agricultural regulation within their borders, and bee disease is primarily a local agricultural problem. The federal government exercises authority at the margins — importation, pesticide registration, honey food safety — but not over the daily registration, inspection, and disease reporting framework. Consequences: a beekeeper operating in two states must be registered separately in each, must comply with each state's notifiable disease list and inspection requirements, and cannot assume that a practice or exemption that applies in one state carries over to the next. A beekeeper moving permanently to a new state must relearn the apiary regulatory framework for that state from the state's own sources.

- Legal obligations upon confirmed AFB diagnosis: Report to the state apiary inspector promptly — failure to report is itself a violation of state apiary law in states where AFB is notifiable. The inspector will arrange a confirmatory inspection, issue a quarantine order restricting movement of equipment from the location, and determine the scope of destruction required. Combs and infected colonies must be destroyed, normally by burning. Woodenware may, where state rules allow, be scorched or paraffin-dipped, or irradiated where a facility exists. Equipment must not be treated with antibiotics, because antibiotics suppress the vegetative stage of *Paenibacillus larvae* but do not kill spores, which remain viable in comb and woodenware for decades. Burning destroys spores in the equipment being burned; burying, dumping, or storing contaminated equipment does not. In some states the beekeeper may be required to do the burning under the inspector's supervision; in others the inspector directs the process. The beekeeper must not move equipment from the quarantined location until the order is lifted.

- An inspector under a typical state apiary act is authorized to enter premises where bees or beekeeping equipment are kept, open colonies, examine bees and brood, take samples, document findings, issue certificates, and issue quarantine or destruction orders where the law and findings support them. The inspector is not authorized to provide advisory or consulting services, promise regulatory outcomes, or exceed the entry and inspection powers the statute grants. A beekeeper who refuses an inspector lawful access is in violation of state apiary law. The inspector can document the refusal and the department can pursue enforcement action, which can include fines and, in some jurisdictions, mandatory inspection under court order.

- Before moving colonies interstate for pollination, the beekeeper should: (1) contact the destination state's apiary regulatory authority and confirm current entry requirements, including the specific diseases the certificate must address, the validity period, any Africanized bee documentation required, and any permit or advance notification requirement; (2) schedule the inspection with the origin state's apiary inspector far enough in advance to get the certificate before the move date; (3) ensure the certificate is dated within the validity period that will apply when the truck arrives, not just when it departs; (4) carry the original certificate with the load; and (5) confirm whether the destination state requires registration of in-state colonies during the pollination stay. Documents in hand at the state line: certificate of inspection from the origin state apiary inspector, any destination state entry permit, and any documentation of Africanized bee status if required.

- Adding a wholesale account and an online store takes the beekeeper outside the cottage food exemption in most states, because cottage food provisions cover direct-to-consumer sales only and do not cover sales to retailers for resale or shipments to buyers who may be in other states. The beekeeper will need to determine: whether the state requires a food processor's license or separate honey processor's license for wholesale operations; what facility inspection or food safety plan requirements apply; whether an internet platform that facilitates interstate shipment makes federal FSMA requirements applicable; what federal labeling requirements apply to products entering interstate commerce; and whether any state cottage food provisions remain available for the direct-sales portion of the business separately from the wholesale and internet portions.

- The Honey Bee Act of 1922 did not prevent the establishment of tracheal mite or Varroa, and that fact should not be used to argue the act is ineffective or should be repealed. Quarantine measures reduce the frequency and delay the timing of introductions; they do not guarantee exclusion from a country as large and with as active an import trade as the United States. The relevant counterfactual is not "would the act have prevented all introductions forever" but "what would the situation be if no import controls existed at all." The act currently prevents the importation of adult bees from most countries, which is the primary barrier to the introduction of *Tropilaelaps* and other exotic pathogens. The case for maintaining the act rests on what it continues to exclude, not on the historical record of what it failed to exclude.

- Theories: negligence (the beekeeper failed to exercise reasonable care in siting or managing the colonies) and private nuisance (the operation substantially and unreasonably interferes with the neighbor's use of her property). Management and siting measures that reduce exposure under both: requeen defensive colonies promptly without waiting for behavior to worsen; provide a reliable on-site water source to reduce bees' use of the neighbor's yard or pool; install a flyway barrier at least 6 feet tall to redirect departing bees above head height across the property line; site hives facing away from the property line and away from outdoor activity areas on both sides; practice active swarm control to prevent swarms from landing in the neighbor's yard; screen the apiary from view to reduce neighbor awareness and conflict; maintain communication with the neighbor; carry liability insurance; and comply with all applicable local ordinances and state registration requirements.

- Correct sequence: (1) Immediately freeze samples of dead bees and any comb fragments with residue-bearing deposits — do not let them sit at ambient temperature, which accelerates residue degradation; (2) photograph the scene with timestamps and GPS coordinates, including hive entrance debris, dead bees in front of the hive, and any drift pattern; (3) do not send

samples to a private laboratory independently — doing so breaks chain of custody, which can undermine an enforcement case; (4) contact the state lead pesticide agency and the state apiary inspector, explain the situation, and follow their instructions for official sample submission; (5) document what you can learn about nearby applications — what crop was being treated, by whom, with what product — but do not confront the applicator before the agency is involved. The order matters because residues degrade over hours and days, chain of custody is required for enforcement, and agencies need to initiate their own investigation rather than inheriting a compromised evidentiary trail.

- The four contributors are: the Bee Informed Partnership (BIP), which ran the national loss and management surveys for more than a decade and whose reports remain the historical series; Auburn University, which now leads the survey as the U.S. Beekeeping Survey and is the source of current loss figures; Oregon State University, its partner in running the survey; and the Apiary Inspectors of America (AIA), which contributes through its network of state inspectors and its role in coordinating the regulatory community's response to colony health data. Current results are released by the lead universities and through AIA communications and Extension channels.

- The written examination establishes whether the candidate has the knowledge base — facts, mechanisms, regulatory frameworks, organizational context. The field examination establishes whether the candidate can actually apply that knowledge to a live colony under conditions they have not controlled: an unfamiliar hive, bees they have never worked before, and the pressure of being evaluated. A candidate who knows the signs of American foulbrood from a textbook must also be able to find suspect cells, assess them under field conditions, and report findings correctly without talking themselves out of what they see. The oral examination establishes whether the candidate can communicate accurately to both beekeeping audiences and general audiences, including being honest about uncertainty. These three competencies are not equivalent and cannot substitute for one another.

- Three frameworks apply. State right-to-farm statute: whether this preempts the municipal ordinance depends on how the state's statute is written and how courts have interpreted its application to residential beekeeping; this is uncertain and requires state-specific legal analysis. Municipal ordinance: as a public law provision, the ordinance is presumptively valid and enforceable unless preempted by state law; absent a clear right-to-farm argument that has been tested in courts, the beekeeper is probably in violation of the two-hive limit. HOA covenant: the covenant is a private contract entirely separate from public law; right-to-farm statutes do not affect private covenants; if the HOA covenant prohibits farm animals and that provision is interpreted to include bees, the beekeeper may be in breach of the covenant regardless of what the public ordinance or state statute says. The neighbor is the HOA member here, which adds further complexity to enforcement.

- Before January 2017, a beekeeper who saw questionable brood could buy oxytetracycline over the counter and dust it on the colony, suppressing symptoms without ever knowing whether the cause was American foulbrood, European foulbrood, nutritional stress, or something else. The VFD requirement removed that option. To use an antibiotic legally, the beekeeper now needs a veterinarian who is willing to write the prescription or VFD, and the veterinarian needs a diagnosis to justify the prescription. That requirement pushes toward laboratory confirmation rather than empirical treatment. It also pushes toward reporting: if the diagnosis is American foulbrood, the inspector needs to know regardless of what the treatment plan is, and the laboratory result provides the documented basis for the inspector's quarantine and destruction

determination. The regulatory change and the reporting obligation thus reinforce each other in pushing toward the correct diagnosis-first approach.

18.17 Further Reading

Federal law and regulation - Honey Bee Act of 1922, 7 U.S.C. 281-286. The foundational importation restriction statute. - USDA APHIS Honey Bee Import Requirements. Current regulations and approved country lists maintained at aphis.usda.gov. - EPA, *Federal Insecticide, Fungicide, and Rodenticide Act* (FIFRA). Statutory text and implementing regulations at 40 CFR parts 150-189. - US FDA, "Proper Labeling of Honey and Honey Products." Final guidance, 2018. Available at fda.gov. - US FDA, "Preventive Controls for Human Food." 21 CFR part 117. The FSMA rule that applies to registered food facilities, such as packers who buy or blend honey from others.

Apiary law and inspection - Apiary Inspectors of America (AIA). State apiary law summaries and inspector directory at apiaryinspectors.org. The most useful single reference for state-by-state regulatory comparisons. - Shimanuki H, Knox DA. *Diagnosis of Honey Bee Diseases.* USDA Agriculture Handbook AH-690, 2000. The standard reference for disease identification under regulatory conditions.

Disease and regulatory intersection - Graham JM (ed.). *The Hive and the Honey Bee.* Dadant & Sons, 2015. The section on apiary regulation by state is the most comprehensive treatment in a standard reference. - Delaplane KS, Hood WM. "Economic threshold for Varroa jacobsoni Oud. in the southeastern USA." *Apidologie*, 30(5): 383-395, 1999. Classic southeastern threshold work; foundational for understanding why thresholds are seasonal.

Honey sales and food law - University of Georgia Cooperative Extension. Publications on Georgia cottage food law and honey sales regulations. Check for current edition at extension.uga.edu, as state requirements change. - University of Florida IFAS Extension. Honey production and marketing publications, including Florida cottage food and honey labeling guidance. - NC State Extension. Apiculture publications, including state-specific regulatory summaries for beekeepers in the Carolinas.

Organizations and certification - Eastern Apicultural Society (EAS). Master Beekeeper program requirements and examination guidelines. Available at easternapiculture.org. - Honey Bee Health Coalition. *Tools for Varroa Management*, 9th edition, June 2026. Available at honeybeehealthcoalition.org. The current standard reference for Varroa monitoring and treatment guidance. - Bee Informed Partnership. Annual colony loss reports at beeinformed.org: the historical loss series through 2022-23. U.S. Beekeeping Survey (Auburn University with Oregon State University and the Apiary Inspectors of America). Current national colony loss figures, at apiaryinspectors.org/US-beekeeping-survey. - Lamas ZS, Rinkevich FD, Garavito A, et al. "Viruses and vectors tied to honey bee colony losses." *PLOS Pathogens* 22(2): e1013939, 2026. The 2026 study finding the Y215H amitraz-resistance genotype in all 39 mites screened from operations that relied mainly on amitraz.

Chapter 19. Safety, Stings & Public Relations

Covers exam questions Q332-Q340.

19.1 Orientation

Safety and public relations sit at the edges of most beekeeping curricula — tacked on after the biology, the disease management, and the honey harvest — and that placement undervalues them. At master level, these topics are not afterthoughts. An examiner probing this chapter wants to know whether you can distinguish a large local reaction from early anaphylaxis, whether you understand why speed matters more than technique when removing a sting, whether you appreciate that heat stroke is a medical emergency that looks nothing like heat exhaustion, and whether you can represent honey bees accurately to a neighbor who thinks they are going to die. Each of those is a judgment call under time pressure, and getting any one of them wrong has consequences that chemistry and hive management rarely produce.

Three ideas organize everything in this chapter. First, sting reactions exist on a spectrum with mechanistically distinct categories, and the exam will test whether you can locate someone on that spectrum and respond correctly to each category. Second, protective equipment and the smoker are tools with trade-offs, not talismans — using them without understanding those trade-offs creates new hazards while reducing the old ones. Third, master beekeepers are the public face of the craft, and accuracy in public communication is not diplomacy; it is the technical obligation that comes with knowing more than the person asking.

A note about the southeastern US context: the region's heat and humidity, its longleaf pine landscapes where wildfire moves fast, and Africanized honey bees (established in Florida, western Louisiana, and Texas, with a climate elsewhere in the region that could support them) all shape what "good safety practice" means here in ways that differ from a temperate, northern context. The heat and the fire risk get dedicated attention in this chapter because the exam is built for this region.

19.2 Venom Biochemistry and the Normal Sting Reaction

When a honey bee stings, the barbed lancets of the sting apparatus lock into skin and the entire sting apparatus detaches, pulling the venom sac and musculature with it. The sac continues to pump rhythmically for approximately sixty seconds, driving venom through the lancets. The composition of that venom determines both the normal reaction and the allergic one.

Melittin accounts for roughly half the dry weight of honey bee venom. It is a peptide that disrupts lipid bilayers in cell membranes, causing immediate pain, local inflammation, and the characteristic burning sensation. Phospholipase A2 is the main sensitizing allergen — the protein that triggers IgE production in susceptible individuals and that is responsible for anaphylactic reactions on subsequent exposures. Other constituents include apamin (a neurotoxin at high doses), histamine (present in small amounts but less significant to the allergic reaction than the body's own mast-cell-released histamine), and hyaluronidase, which facilitates the spread of other components through tissue.

Every person who is stung will have a normal reaction: local pain, redness, and swelling at the sting site, peaking within an hour and resolving within a day or two. This is a toxic response to the pharmacologically active compounds in venom, not an allergic one, and it does not differ in mechanism between a beekeeper who has been stung ten thousand times and someone stung for the first time. Experienced beekeepers often notice that the acute pain diminishes after repeated exposure, which probably reflects immune changes (rising venom-specific IgG4) as well as habituation. It is not a guarantee against new sensitization. The important point is that a normal reaction, however uncomfortable, is self-limiting and requires no medical intervention beyond ice and an oral antihistamine for swelling if the person finds it helpful.

19.3 Large Local Reactions: What They Are and What They Are Not

A large local reaction (LLR) is an exaggerated local response to a sting. Swelling extends well beyond the immediate sting site — by convention, more than ten centimeters across — and the reaction peaks between twenty-four and forty-eight hours after the sting rather than within the first hour. The swelling is contiguous with the sting site and may involve an entire limb or the face around a single sting. It is uncomfortable and alarming, and it commonly prompts beekeepers and their associates to believe that anaphylaxis is occurring or imminent.

The mechanism is IgE-mediated, meaning sensitization to venom allergens (principally phospholipase A2) has occurred and the response is genuinely allergic. But the reaction is confined to tissue at and around the sting site. Mast cells there degranulate in response to antigen-antibody bridging, releasing histamine and other mediators locally, producing local edema and inflammation. What does not occur is systemic mast cell activation. There is no generalized histamine release, no bronchospasm, no vascular collapse.

The critical clinical and epidemiological fact is that a large local reaction does not predict systemic anaphylaxis on a subsequent sting. Studies of individuals with histories of LLR who are re-stung find that they are slightly more likely to have another LLR and have about a 5 to 10 percent chance of a systemic reaction on a later sting. That is a low risk, but not zero, and it is not substantially elevated compared to the general sensitized population. This means that a beekeeper who swells dramatically after a sting should be evaluated by a physician, but should not be told their beekeeping is over. Venom immunotherapy is not routinely indicated for LLR alone, but an allergist may consider it for beekeepers or others with frequent, severe, or disabling large local reactions and continuing exposure. The beekeeper should understand the distinction between their reaction and anaphylaxis so they can monitor themselves accurately.

19.4 Systemic Anaphylaxis: Mechanism, Recognition, and Emergency Response

Anaphylaxis is a systemic, IgE-mediated hypersensitivity reaction in which mast cells throughout the body degranulate simultaneously. The trigger is the same — phospholipase A2 bridging IgE antibodies on mast cell surfaces — but the response is not confined to tissue near the sting. Mast cells in the skin, lungs, gut, and vasculature all respond, releasing histamine, leukotrienes, prostaglandins, and platelet-

activating factor simultaneously. The result is a cascade: vasodilation drops blood pressure, capillary leak moves fluid out of vessels, bronchospasm closes airways, and urticaria (hives) appears on skin remote from the sting site.

The distinguishing feature of anaphylaxis — the exam's key concept in Q332 — is that symptoms appear at a distance from the sting site. Any systemic sign: hives on the trunk when stung on the hand, throat tightening, difficulty breathing, lightheadedness, nausea, or a sensation of impending doom, means anaphylaxis until proven otherwise. A sting on the hand that produces dramatic swelling of the entire arm, but nothing else, is a large local reaction, not anaphylaxis, regardless of how frightening the arm looks.

Recognizing anaphylaxis is complicated by two common confounders. First, anxiety after a sting is normal, particularly in someone who has had a previous reaction or has been told they are allergic. Hyperventilation from anxiety can cause tingling in the hands and feet and lightheadedness. Second, a vasovagal response — a common faint triggered by pain, fear, or the sight of blood — can cause pallor, a drop in blood pressure, slow heart rate, and loss of consciousness. A vasovagal response typically resolves quickly when the person lies down, the heart rate is slow (bradycardia), and there are no skin signs away from the sting. Anaphylaxis produces tachycardia (fast heart rate), does not resolve with supine positioning alone, and frequently includes the skin signs of urticaria or angioedema. The distinction matters because the management is opposite: a vasovagal patient should lie down and recover; an anaphylactic patient needs epinephrine immediately. The error of dismissing early anaphylaxis as a panic attack or a faint has cost lives.

The only first-line treatment for anaphylaxis is epinephrine, administered by intramuscular injection into the outer thigh. Epinephrine reverses bronchoconstriction through beta-2 adrenergic agonism, raises blood pressure through alpha-1 adrenergic vasoconstriction, and stabilizes mast cells to reduce further mediator release. These effects are achievable only by the injected drug; oral antihistamines cannot reverse bronchoconstriction or vascular collapse and must never be presented as treatment for anaphylaxis. Antihistamines are an adjunct — they may slow secondary mediator effects — but they are not a substitute for epinephrine and should never delay its use.

Correct management of a witnessed anaphylactic episode at an apiary: inject epinephrine into the outer thigh using an auto-injector if available; call emergency medical services immediately (know your address and whether cell service is reliable before you work bees); lay the person down with legs elevated unless respiratory symptoms require them to sit up; remove the sting; be prepared to give a second dose if there is no improvement in five to fifteen minutes and a second injector is available; and ensure that the person reaches a hospital for observation even if symptoms improve, because biphasic reactions (recurrence hours later) are possible. Do not allow someone who appears to have recovered from anaphylaxis to drive home.

Every beekeeper with a documented systemic reaction should carry two auto-injectors of epinephrine, see an allergist, and discuss venom immunotherapy. Every apiary at which novices or visitors are routinely present should have an emergency plan that includes the location of the nearest epinephrine, the address of the apiary, and a route to the nearest emergency department.

19.4.1 Venom Immunotherapy

Venom immunotherapy (VIT) is subcutaneous desensitization carried out under allergist supervision. The protocol involves injections of increasing doses of purified venom, typically over months, until a maintenance dose is achieved. Controlled trials and retrospective series document protection rates of roughly 77 to 84 percent for honey bee venom specifically — vespid (wasp and yellowjacket) venom VIT runs higher, at 91 to 96 percent. Even at the honey bee figure, VIT is among the more effective immunotherapy procedures in medicine. It results in genuine immune tolerance, shifting the response from an IgE-mediated allergic pattern toward IgG-mediated blocking antibody. A beekeeper who has had a systemic reaction and completes VIT can return to beekeeping with substantially reduced risk. VIT is not a DIY procedure and is not available over the counter; it requires an allergist, standardized venom extracts, and a monitored setting because the injections themselves cause systemic reactions in a minority of patients (more often with honey bee venom than with wasp venom), usually mild and treatable in the clinic. The master beekeeper who mentors others should be prepared to explain VIT accurately and to encourage allergic beekeepers to pursue it rather than quit the craft.

19.5 Sting Removal: What the Evidence Shows

The traditional teaching — always scrape the sting with a hive tool, never pinch it — is rooted in a mechanistic concern that pinching the venom sac would inject its remaining contents in a bolus. That reasoning seems logical, but a small experiment published in *The Lancet* in 1996 by Visscher, Vetter, and Camazine tested the question directly. Three volunteers were stung in controlled conditions; stings were removed after 0.5 to 8 seconds and by different methods (scraping versus pinching with fingers or tweezers). The amount of venom injected, measured by wheal size as a proxy for dose, rose with the time elapsed, while scraping versus pinching made no significant difference. The venom sac has a defined delivery rate. The study is small, but its practical conclusion is sound.

The practical instruction for the exam and for the field is: remove the sting immediately, by whatever means is fastest. A hive tool or fingernail is convenient; if neither is in reach, pinch it out. Hesitation to find the ideal method while the sac continues pumping is the one thing the evidence identifies as harmful. A beekeeper who interrupts another task to lecture on scraping technique while someone stands with a sting delivering venom has the priority precisely wrong.

19.6 Mass Envenomation: A Toxic, Not Allergic, Event

When a large number of stings is delivered — as can occur in an attack by a highly defensive colony, particularly one with Africanized genetics, or when someone stumbles into a large feral nest — the sheer pharmacological load of venom produces systemic toxic effects entirely independent of allergy. This is not an allergic reaction; it can happen to a non-allergic person who has been stung thousands of times before and built partial tolerance to ordinary stings.

The mechanism is direct toxicity of venom components at high concentration. Melittin at high systemic doses disrupts red blood cell membranes (hemolysis), damages muscle cells (rhabdomyolysis), and impairs kidney filtration. Phospholipase A2 contributes to systemic inflammation. The clinical course includes muscle pain, vomiting, fever, and can progress to acute kidney injury, cardiovascular effects,

and shock. Critically, these effects can develop over hours to days rather than immediately, which means someone who has been massively stung but walks away from the scene feeling shaky may deteriorate later.

There is no single threshold, and it is much lower than most people assume. Adults who receive more than roughly 15 to 25 stings should be medically evaluated, and children, older adults, and anyone with heart or kidney disease should be evaluated after far fewer. Anyone with vomiting, muscle pain, dark urine, breathlessness, or faintness after multiple stings should go to an emergency department, and anyone stung several hundred times (about 500 stings is potentially life-threatening for an adult) should be transported there for evaluation, bloodwork, and observation even if their initial symptoms seem manageable. Individual responses vary, but the exam concept is clear: this is a toxic dose-response event, not an allergic one, and the treatment is supportive hospital care rather than epinephrine (though epinephrine would be appropriate if allergic features also appeared). The risk is greatest with colonies that are Africanized or highly defensive, in confined spaces where escape is difficult, and in situations where a person cannot respond normally to the attack (children, the elderly, people with mobility impairments).

19.7 Protective Equipment: Trade-offs and the One Non-Negotiable

The exam item for Q337 targets two opposite errors that master beekeepers encounter regularly: over-reliance on equipment as a substitute for technique and temperament management, and dismissal of equipment as unnecessary for experienced beekeepers. Both views are wrong for the same reason: equipment is a tool with trade-offs, not an absolute solution or an obstacle to skill.

The veil is the one genuinely non-negotiable piece of equipment. Bees targeting a defensive encounter preferentially sting at the face and neck, where dark features, movement, and breath carbon dioxide concentrate alarm stimuli. A sting near the eye, airway, or ear canal is categorically more serious than a sting on a gloved hand. No degree of experience, gentle stock, or calm technique makes the face and neck as acceptable a sting target as a forearm. The veil is minimum equipment; working without one with unfamiliar colonies, defensive genetics, or in public-facing teaching contexts is not an expression of skill but of poor risk calibration.

Gloves involve genuine trade-offs. Leather gloves protect well but substantially reduce tactile feedback and dexterity. A beekeeper who cannot feel through gloves crushes more bees, and crushed bees release alarm pheromone, which recruits more defensive behavior. Many experienced beekeepers use nitrile or thin rubber gloves, which accept occasional stings but preserve enough dexterity to minimize bee crushing. Others work gloveless on known gentle colonies in good weather. The judgment depends on the colony, the day, and the consequence of a sting to the hands. For a beekeeper with a history of LLR from hand stings, or for anyone working a colony with unknown temperament, gloves are the correct choice.

Full suits substantially reduce sting frequency and are appropriate for defensive colonies, teaching situations, or any scenario where a compromised reaction to stings would be hazardous. In the southeastern US heat, a full suit adds significant thermal burden. Ventilated suits are now widely

available and reduce but do not eliminate that burden. The interaction between protective clothing and heat illness is not theoretical: a beekeeper who works through midday in August in a full unventilated suit while already dehydrated is trading one hazard for another.

Bees respond more defensively to dark colors, to movement, and to the odor of alarm pheromone. Light-colored suits reduce defensive behavior at the margin. This is not a reason to skip a dark-colored suit if it is the only one available, but it explains the historical preference for white beekeeping clothing.

19.8 The Smoker: Mechanism, Fuels, and Fire Safety

The smoker is the fundamental tool of bee management, and its use involves both a biological mechanism and a fire safety obligation that the exam addresses directly in Q338.

The mechanism: smoke reduces the bees' ability to detect isoamyl acetate (antennal responses fall by about half for 10 to 20 minutes), the primary alarm pheromone released by guard bees when they sting or when a colony is disturbed. Without the signal, the cascade of defensive recruitment is interrupted and additional guards do not mobilize. A traditional explanation adds that smoke triggers a feeding response in which bees gorge on honey in preparation to flee a fire, making them less inclined to sting, but this has not been well demonstrated experimentally. The effect is not permanent; smoke buys time. Once the smoke dissipates and alarm pheromone accumulates, defensive behavior will resume. A beekeeper who enters a colony briefly, applies smoke at the right moments (the entrance, under the cover, between boxes), and works steadily and calmly manages this window effectively. A beekeeper who smokes once and then works slowly for an hour is relying on a depleted effect.

Cool, white smoke is the target. Hot smoke or flame drives bees off combs, damages comb, and provokes rather than calms. The difference between cool and hot smoke is a function of fuel moisture, airflow, and whether the smoker is managed or ignored. Dry natural fuels — wood shavings, untreated burlap, dried pine needles, commercial smoker pellets — produce the right smoke when the smoker is fed and pumped correctly. Synthetic materials, painted wood, treated lumber, and anything with chemical contaminants can produce toxic fumes that harm the beekeeper, harm the bees, and can leave residues in hive products.

Fire safety for the smoker is a serious concern in the southeastern US. The longleaf and loblolly pine landscapes that characterize the coastal plain and piedmont carry significant wildfire risk, particularly in drought conditions, and open burning restrictions apply seasonally and sometimes year-round in these areas. Specific fire safety obligations:

- Never set a lit smoker on dry grass, pine straw, or leaf litter, even briefly.
- Transport a lit or recently lit smoker in a closed metal smoker box or sealed metal container that starves it of air. An improperly transported smoker that tips over in a vehicle has caused vehicle fires and apiary fires.
- Before leaving the apiary, ensure the smoker is completely extinguished — this means no glow, no heat, no residual smoke. A smoldering smoker left at a bee yard in dry conditions can ignite surrounding material over hours.

- Keep water or a small fire extinguisher accessible at the apiary.
- Be aware that a hot smoker body will burn skin as readily as any metal tool.

These are not advisory cautions for exceptional conditions. They are standard practice for any apiary in the region.

19.9 Heat Illness: The Underappreciated Hazard

Of all the occupational hazards in beekeeping, heat illness is the most consistently underestimated, and in the southeastern US it is arguably more dangerous than stings for most beekeepers working regularly in summer. The combination of high ambient temperature, high humidity, protective clothing that prevents evaporative cooling, and the exertion of lifting and manipulating hives creates conditions in which body temperature can rise faster than many beekeepers recognize.

The key physiological point is that evaporative cooling is the body's primary heat dissipation mechanism in hot conditions. In the southeastern US, summer afternoons combine air temperatures in the 90s F with dew points in the 70s, so the heat index is dangerously high even though relative humidity is lower than at dawn. In that air, sweat cannot evaporate efficiently, and the cooling effect is lost even though the beekeeper is sweating heavily. A beekeeper who feels drenched in sweat may not be cooling effectively at all. Add a full suit and the situation worsens: the suit traps humid air against the skin, further suppressing evaporative cooling.

Heat illness progresses through recognizable stages that the beekeeper must understand:

Heat cramps are muscle cramps resulting from electrolyte loss in sweat, typically in the legs or abdomen. They are a warning sign to stop, hydrate, and rest in shade.

Heat exhaustion produces heavy sweating, weakness, pallor, nausea, headache, a rapid weak pulse, and cool moist skin. The body is still sweating and still attempting to cool, but the cardiovascular system is struggling. Moving the person to shade, removing excess clothing, and providing cool water and electrolytes usually resolves heat exhaustion, but the person should be monitored and not left alone.

Heat stroke is a medical emergency. The defining signs are confusion or altered mental status and a core temperature above about 104 degrees F, with a rapid, strong pulse. The skin is hot, and sweating may stop, but in exertional heat stroke - the kind a working beekeeper gets - the person is often still sweating, so continued sweating does not rule it out. When sweating does stop, that is not a sign that the beekeeper is getting better or has cooled down; it is an ominous sign that thermoregulation has failed and the body is accumulating heat without defense. Call emergency services immediately. Cool the person by whatever means available — immersion in cold water is the most effective where it is possible; otherwise move to shade, apply ice packs to the neck, armpits, and groin, use wet cloths and fanning — and do not leave them. Heat stroke can cause death or permanent organ damage within a short window.

The reason the buddy system is essential for heat work is that confusion is an early sign of heat stroke. An affected person cannot accurately assess their own condition, cannot call for help reliably, and cannot make decisions about when to stop. If you are working alone in extreme heat and you begin to

feel confused, you cannot self-rescue. Someone must know where you are, when to expect you back, and what to do if you do not return on time.

Prevention: schedule hive work for early morning in summer, when ambient temperature and solar load are lower and the day's peak heat has not built (relative humidity is highest near dawn, so the benefit of an early start is the lower heat load, not drier air); pre-hydrate before going into the yard; drink before feeling thirsty (thirst significantly lags actual dehydration); take scheduled shade breaks regardless of whether you feel you need them; use ventilated suits; never consume alcohol before working hives in hot weather. High-risk groups include beekeepers with cardiovascular disease, obesity, or those taking diuretics, certain antihistamines, or beta-blockers, all of which impair the normal heat response. These individuals should consult their physician about beekeeping in warm conditions.

19.10 Other Occupational Hazards Beyond Stings and Heat

Musculoskeletal injury is the most common occupational injury in beekeeping and the one that ends careers most quietly. A deep Langstroth box full of honey weighs roughly eighty to ninety pounds, a medium roughly fifty to sixty. Lifting one repeatedly, while bending, on uneven ground, while wearing a veil that impairs peripheral vision, is a recipe for back and shoulder injury. The mitigation is structural: use medium or shallow supers; consider eight-frame equipment, which reduces box weight by roughly twenty percent; use a helper, cart, or mechanical lift for heavy loads; work on level ground where possible. Master beekeepers who build out teaching apiaries and scale operations should design for sustainable lifting from the start.

Chemical exposure occurs when handling concentrated organic acids and synthetic acaricides. Oxalic acid used for *Varroa destructor* control is corrosive to mucous membranes; vaporization of oxalic acid without appropriate respiratory protection and proper containment creates genuine hazard. Every chemical treatment used in the hive has a label with specified personal protective equipment requirements, and those requirements reflect toxicological data. Wearing the specified PPE is not optional at master level — it is the standard of practice, and a master beekeeper who skips it while teaching sets the wrong example.

Vehicle and equipment hazards arise during colony moves, which are routine in commercial and migratory contexts and occasionally necessary for hobbyists. Hive loads that are inadequately secured can shift and fail on the road. Nighttime moves, loading and unloading of heavy equipment, and driving with a trailer all require planning and care that busy beekeepers sometimes shortcut under time pressure.

Fire risk from smokers has been addressed in the smoker section, but belongs in any complete occupational hazard inventory.

19.11 Working Alone: Why It Is a Specific Hazard Category

Working alone at an apiary is qualitatively different from other risk exposures because it is the common factor that makes several other hazards unrecoverable. An anaphylactic reaction that begins while you are alone at the hive may be survivable if discovered in time but fatal if not. Heat stroke that produces

confusion while you are alone means no one knows you need help and you cannot effectively call for it. A fall or a bad bee reaction while alone in a remote out-apiary may delay care by hours.

The practical mitigation is simple: tell someone your location and your expected return time before working bees alone, and establish a check-in protocol when you will not return to a fixed location. New beekeepers, beekeepers working in extreme heat, and beekeepers with known allergic histories should not work alone. The buddy system in these contexts is not an abundance of caution but a basic risk control.

19.12 Defensive Colonies: Recognition and Escalation

A defensive colony gives warning before it becomes dangerous, and reading those warnings is a core skill at master level. Guard bees at the entrance that follow the beekeeper at a distance, repeatedly head-butting the veil without landing, are providing an early signal. A colony that begins following you in numbers before you have opened the hive, or that produces loud defensive buzzing immediately on opening without provocation, is telling you the inspection is going to be difficult.

Alarm pheromone — isoamyl acetate, with a scent resembling banana candy — is released from the sting apparatus, at the sting site and whenever guards extrude their stings. It recruits additional defensive bees and lowers the sting threshold of nearby workers. Once significant alarm pheromone is in the air, smoke masks it partially but the colony is primed. A beekeeper who has received several stings in a short period should not push through — the pheromone marking on the veil and clothing will recruit further stinging.

The correct response to an unworkably defensive colony is to close up and leave. Return later in the day, after cooler temperatures and a different wind direction have changed conditions, or return on a different day. Defensive colonies in locations near the public or near neighbors, or colonies that do not respond to good technique and appropriate conditions, warrant requeening with a mated queen from gentle stock. At master level, the decision to requeen a defensive colony is a management judgment, not a defeat.

Post-sting management: remove the sting immediately (by the fastest means available); wash or smoke the stung area to remove pheromone; wash gloves and suit if heavily stung, since pheromone on equipment persists and can trigger defensiveness at the next inspection.

19.13 Public Communication: Accuracy as a Tool

The exam item Q339 tests whether a master beekeeper understands that accuracy in public communication is a technical obligation, not just an ethical one. Overstating the case for honey bee conservation is tempting because it seems to recruit public sympathy, but it is counterproductive in two ways: it makes claims that informed listeners will recognize as wrong, which undermines credibility on every point that follows, and it conflates the genuine conservation concerns about native pollinators with the management economics of a domesticated livestock species.

Honey bees are managed livestock. They are not endangered and are not at risk of extinction. Annual colony losses in the United States — 55.1% in 2023-24 and 55.6% in 2024-25, falling to a preliminary

39.9% in 2025-26, but still far above the 15-20% beekeepers consider acceptable — are a measure of what it costs beekeepers to maintain colony numbers, not evidence that the honey bee is disappearing. Beekeepers replace lost colonies by splitting and requeening; national colony counts have been roughly maintained for decades despite high annual losses. The accurate account — that losses are economically and operationally serious, that Varroa mite management is a central driver, that amitraz resistance is now documented at high frequency, and that beekeepers work hard and at significant cost to sustain colony numbers — is both more honest and more interesting to a thoughtful audience than "bees are dying out."

The genuine conservation concern involves native pollinator species, many of which do not have commercial management and cannot be replaced by splitting. A master beekeeper who is asked about bee decline serves the public best by making that distinction clearly: managed honey bees are a livestock management problem; native bee decline is a habitat and pesticide exposure problem; these are related but not identical.

When speaking to the public about pesticides, beekeeper advocacy is appropriate and well-supported by evidence. But the claim that prohibiting all agricultural pesticides is the single most important intervention overstates the case and misrepresents the complexity of the system. Integrated pest management, pesticide stewardship programs, label compliance, and habitat enhancement are all meaningful levers. A master beekeeper who can speak to these accurately, with appropriate nuance about what is known and what remains uncertain, builds the kind of credibility that actually changes behavior.

19.13.1 Swarm Calls

Swarm calls from the public are a routine duty of any well-known beekeeper, and handling them well is a public relations as much as a beekeeping task. The caller is often frightened; the bees are often not honey bees; and the cluster, if it is honey bees, may have moved on by the time you arrive. Key points for swarm call management:

Teach bee identification over the phone. Honey bees are fuzzy, amber-to-brown, robust insects. Yellowjackets are smooth, wasp-waisted, bright yellow-and-black, and often nest in the ground. Bumble bees are large and very fuzzy. Carpenter bees resemble bumble bees but have a shiny black abdomen. An underground nest producing aggressive insects on a late-summer afternoon is almost certainly yellowjackets, not honey bees; sending the caller to a pest control service rather than arriving to collect "a swarm" prevents a wasted trip and a disappointed caller.

If the swarm is honey bees, explain that a swarm is a natural reproductive event and that the bees are in a temporary, transitional state that makes them unusually docile — they have no comb or brood to defend. Swarms can wait hours to days before moving to a permanent site, but they can also leave quickly if disturbed. Do not promise the caller you will collect it "tomorrow morning" without confirming it is still there.

Maintain a swarm referral list for your area. The first call you cannot take can go to the next name on the list. Local beekeeper associations often coordinate this.

19.14 Neighbor Relations: Water, Flyways, and the Long Game

The neighbor complaint scenario tested in Q340 — bees at a swimming pool — is a specific instance of the broader principle that neighbor relations are a management responsibility. Bees foraging for water will establish reliable routes to any permanent water source within a kilometer or two of the apiary. A swimming pool is an ideal water source from the bee's perspective: large, warm, carrying dissolved salts and a distinctive odor that make it easy for bees to find, and present year-round. Colonies established on a pool as their water source will continue to use it even if you establish alternative sources later, though most eventually shift if the alternative is consistently available, closer, and preferable.

The correct response to a neighbor water complaint is prompt, courteous, in-person, and practical. Go in person, not by phone or text. Acknowledge that the bees are likely yours and that the situation is a nuisance you intend to fix. Explain briefly why it happens. Then offer the concrete fix: establish a reliable, permanent water source at your property, closer to the hives than the pool, with landing surfaces (corks, stones, a wet board, a dripping faucet over a trough). Accept that bees already habituated to the pool will take time — sometimes weeks — to shift. Suggest interim measures: a pool cover or higher filtration schedule can reduce the attractiveness of the pool during the transition.

The wrong response is to dispute whether the bees are yours, to dismiss the problem, or to promise a quick fix and then not follow through. A neighbor who feels ignored will call the municipality. Municipal complaints create legal exposure and sometimes result in ordinance challenges that affect all beekeepers in an area, not just the one whose bees caused the original problem. Proactive relationship management — introducing yourself before problems occur, sharing honey, placing hives with flyways directed away from property lines, and checking applicable local ordinances — prevents most neighbor conflicts from starting.

When flyway management is possible, orient hive entrances so foragers fly upward over a solid fence or dense hedge before reaching the property line. Bees flying at six feet or higher are essentially invisible to people who do not know to look for them. A six-foot solid fence or a row of fast-growing arborvitae or wax myrtle accomplishes this effectively.

19.15 Numbers to Know Cold

Figure	Value	Why it is that value
Large local reaction threshold	>10 cm across, contiguous with the sting site	Arbitrary but standardized clinical criterion separating LLR from normal swelling
LLR peak timing	24-48 hours post-sting	Slower IgE-mediated local mast cell cascade vs. immediate toxic response
LLR resolution	Several days to a week	Tissue edema and local inflammation resolve as mediators clear
VIT efficacy	~77-84% (honey bee venom); 91-96% (vespid venom)	Subcutaneous desensitization achieves high-level immune tolerance; honey bee venom protection is lower than vespid

Figure	Value	Why it is that value
Venom sac pumping duration	~60 seconds	Rhythmic muscular contraction after sting apparatus detaches
Melittin fraction of venom dry weight	~50%	Dominant peptide; responsible for immediate pain and membrane disruption
Second epinephrine dose interval	5-15 minutes	Time allowed to assess response to first dose before repeating
Heat stroke core temp (approximate)	>104 degrees F	Threshold at which enzyme systems and cellular integrity are at risk
Biphasic anaphylaxis recurrence window	Most within 8-12 hours; documented cases to 72 hours	Reason for in-hospital observation even after apparent recovery
Alarm pheromone	Isoamyl acetate	Chemical identity of primary bee alarm pheromone; “banana” odor
Venom immunotherapy maintenance duration	Typically 3-5 years	Duration of maintenance phase for sustained protection
Heavy super weight	80-90 lbs (deep); 50-60 lbs (medium)	Full box of honey; key number for ergonomic planning
Swarm docility window	Hours to a couple days	Period before swarm locates and moves to permanent site
VIT protection onset	After maintenance dose achieved	Not immediately protective; sensitized beekeeper must carry epi during treatment

19.16 Common Misconceptions

Misconception: If someone swells a lot from a sting, they have a dangerous allergy and should not be around bees. **Correction:** A large local reaction, however dramatic, is confined to tissue near the sting site. It does not predict systemic anaphylaxis and is not itself dangerous in the same way. A physician’s evaluation is appropriate, but the reaction alone does not mean the person cannot continue beekeeping. VIT is not routinely indicated for LLR without systemic history, though an allergist may consider it for beekeepers with frequent or disabling LLRs.

Misconception: When removing a sting, you must scrape it and never pinch it, because pinching injects all the venom at once. **Correction:** A small controlled experiment (Visscher et al., 1996; three volunteers) found that venom dose delivered rose with time elapsed after the sting and was not significantly affected by removal method. The sting sac empties at a fixed rate. Method did not significantly affect dose in that experiment. Remove by the fastest means available; do not hesitate.

Misconception: Antihistamines are the appropriate first treatment for anaphylaxis. **Correction:** Antihistamines block histamine receptors but cannot reverse bronchoconstriction or vascular collapse. They are an adjunct that may blunt secondary effects, not a treatment for anaphylaxis. Epinephrine is

the only first-line treatment, and administering antihistamines while withholding or delaying epinephrine is dangerous.

Misconception: A beekeeper who has been stung thousands of times without a serious reaction will never develop anaphylaxis. **Correction:** Sensitization can develop at any point in a beekeeper's career. The fact that previous stings produced only normal reactions does not confer lifetime protection. Beekeepers who experience new or unusual symptoms after a sting should not dismiss them on the basis of prior experience.

Misconception: If someone stops sweating, the heat danger has passed and they are cooling down. **Correction:** Cessation of sweating in a heat-stressed person is a late and ominous sign of heat stroke, indicating that thermoregulatory mechanisms have failed. Heat is now accumulating without any cooling response. This is a medical emergency requiring immediate cooling and emergency medical services. The reverse does not hold either: in exertional heat stroke many people are still sweating, so confusion in a hot, exerting person is the sign to act on.

Misconception: A full suit means you can work through any colony without worrying about bee behavior, weather, or technique. **Correction:** A full suit reduces sting frequency but does not eliminate defensive behavior and creates a heat illness risk. Colony behavior, weather, and technique still matter. Rough handling of a defensive colony in a full suit still produces alarm pheromone, still drives the colony to search for gaps, and still creates a stressful inspection. Equipment does not substitute for management.

Misconception: Never wear gloves, because gloves reduce dexterity and real beekeepers do not need them. **Correction:** Gloves involve genuine trade-offs, and experienced beekeepers make different judgments about them depending on context. But presenting gloveless beekeeping as a mark of skill that others should emulate, particularly with unfamiliar colonies or in public settings, is poor risk communication. Nitrile or thin rubber gloves offer reasonable protection with limited dexterity loss.

Misconception: Honey bees are endangered and face imminent extinction, which is why we need to "save the bees." **Correction:** Managed honey bees are a livestock species maintained by commercial and hobbyist beekeepers. Annual colony loss rates are high (39.9-55.6% in recent survey years) and costly, but colony numbers nationally have been maintained because beekeepers replace lost colonies. The genuine conservation concern involves native pollinator species, many of which cannot be commercially managed. Conflating the two undermines credibility and misdirects conservation concern.

Misconception: A swarm of bees is extremely dangerous and requires pest control to eliminate. **Correction:** A swarm in transit is at its most docile state: the colony is clustered around a queen, has no comb or brood to defend, and the bees are gorged with honey. The appropriate response is to contact a local beekeeper who may be able to collect the swarm. Pest control is warranted for a swarm that has entered a structure and begun building comb.

Misconception: Mass stinging is dangerous only to people with bee allergies. **Correction:** Mass envenomation is a toxic, not an allergic, phenomenon. Large doses of melittin and phospholipase A2 cause direct tissue damage — hemolysis, rhabdomyolysis, kidney injury — independent of any allergic

sensitization. Beekeepers with high sting tolerance are not protected against toxic dose effects. Adults stung more than roughly 15 to 25 times, and children, older adults, or people with heart or kidney disease after far fewer, should receive medical evaluation regardless of allergy history; several hundred stings (about 500 in an adult) is potentially life-threatening.

Misconception: The smoker calms bees by sedating them. **Correction:** Smoke reduces the bees' ability to detect isoamyl acetate (alarm pheromone), interrupting the defensive recruitment cascade; a traditional explanation adds a feeding/gorging response in preparation to flee a fire, but this has not been well demonstrated. Bees are not sedated; they are behaviorally redirected. The effect is time-limited and requires the smoker to be maintained and used appropriately throughout the inspection.

Misconception: Responding to a neighbor complaint by explaining that bees are docile and harmless is the right approach. **Correction:** A neighbor who is experiencing bees at their pool or in their yard does not need to be educated about bee gentleness — they need the problem resolved. The correct approach is to acknowledge the problem, provide the practical fix (a reliable alternative water source close to the hives), and follow through. Lecturing a frustrated neighbor about bee behavior is not a conflict resolution strategy.

19.17 Self-Check Questions

- Explain the mechanism by which a large local reaction differs from anaphylaxis at the cellular level. Why does a dramatic LLR not predict that the person will have anaphylaxis on re-sting?
- A new beekeeper is stung on the hand and within ten minutes complains of feeling faint, becoming pale, and having a slow pulse. She lies down and the symptoms resolve in a few minutes. What is the most likely diagnosis and why? What would change your assessment toward anaphylaxis?
- You are demonstrating hive management to a group of new beekeepers when a participant is stung and rapidly develops urticaria across her trunk and reports throat tightening. Walk through your complete response, in order.
- Describe what controlled experiments show about the best method for removing a sting from skin. What is the practical instruction that follows from this evidence?
- A beekeeper says: "I've been stung five thousand times over thirty years and never had more than normal local reactions, so I don't need to carry an EpiPen." Evaluate this reasoning.
- Distinguish heat exhaustion from heat stroke on three clinical dimensions, and state what makes heat stroke a medical emergency while heat exhaustion is not.
- A neighbor tells you that your bees have been congregating at his pool for three weeks. Describe your immediate response and the practical steps you would take over the following month.
- Why is working alone at an apiary in summer specifically more hazardous than working alone at an apiary on a mild fall day? Name two distinct scenarios that illustrate the difference.
- A member of the public approaches you at a county fair and asks whether it is true that honey bees are going extinct. Compose a two-minute accurate response.

- Explain why the smoke from a smoker using wet or synthetic fuel is specifically problematic compared to smoke from dry natural fuel.
- A student beekeeper asks whether she should always wear leather gloves. What guidance would you give, and what reasoning would you use?
- Describe how you would recognize a colony that is becoming unworkably defensive before the situation escalates, and what you would do.

19.18 Self-Check Answers

- In a large local reaction, mast cells at and near the sting site degranulate in response to IgE antibodies bound to venom antigens (primarily phospholipase A2). The reaction is locally amplified but spatially contained — systemic mast cell activation does not occur. Anaphylaxis requires simultaneous degranulation of mast cells throughout the body, including in the lungs, gut, and vasculature, producing generalized effects. The LLR and anaphylaxis share IgE-mediated mechanism but differ in whether the antigen exposure triggers only local or also systemic mast cell response. Epidemiological data confirm that people with LLR histories have about a 5 to 10 percent chance of a systemic reaction on a later sting, a low but not zero risk that is not substantially elevated compared to other sensitized individuals, which makes LLR a poor predictor of anaphylaxis and means it should not be treated as if it were a near-miss systemic event.
- The most likely diagnosis is a vasovagal (syncope) response: pallor, slow pulse (bradycardia), and rapid resolution with supine positioning are characteristic. Vasovagal responses are common after painful stimuli in people with no sting allergy history. What would shift the assessment toward anaphylaxis: tachycardia (fast pulse) rather than bradycardia; failure to resolve promptly with lying down; presence of hives or urticaria on areas remote from the sting; throat tightening, stridor, or wheezing; nausea or vomiting; a sense of impending doom. Any of those signs means treat as anaphylaxis until proven otherwise.
- In order: verbally identify the situation as a possible anaphylactic reaction and direct someone to call 911 immediately. Ask whether the participant has an auto-injector — if yes, obtain it and use it or assist her in using it; if no, identify whether anyone else present has one. Administer epinephrine intramuscularly in the outer thigh. Lay the participant down with legs elevated unless breathing difficulty requires sitting up. Remove the sting from her skin as quickly as possible. Keep her still and do not allow her to stand or walk. Be prepared to give a second dose in five to fifteen minutes if symptoms do not improve and a second injector is available. Ensure EMS transport to hospital even if she improves, because biphasic reactions are possible. Document the time of the sting, the time of epinephrine administration, and the response.
- Visscher, Vetter, and Camazine (1996), in a small experiment with three volunteers, found that the amount of venom injected rose with time elapsed after the sting and was not significantly affected by the method of removal. Scraping and pinching produced equivalent venom doses at equivalent time points. The traditional warning against pinching was not supported. The practical instruction: remove the sting immediately, by whatever means is fastest. Do not hesitate while searching for a hive tool or instructing the ideal technique. Speed governs dose; method does not.

- The reasoning is flawed. Sensitization to venom allergens can develop at any point during a beekeeping career, and having had only normal reactions in the past does not protect against sensitization in the future. New symptoms after a sting — even subtle ones — should prompt evaluation rather than dismissal. Furthermore, even a beekeeper who has genuinely not sensitized over thirty years cannot know in advance whether they have sensitized recently. The consequences of being wrong while unequipped are severe and fast-moving. Carrying epinephrine is low-cost insurance against a high-consequence event; the argument against carrying it on the basis of prior experience is a textbook example of reasoning from an absence of evidence.

- Heat exhaustion versus heat stroke: (1) Sweating: heat exhaustion features heavy sweating; in heat stroke sweating may stop, but in exertional heat stroke it often continues, so sweating is the least reliable of the three signs. (2) Mental status: heat exhaustion produces weakness, nausea, and malaise but cognition is generally intact; heat stroke produces confusion, disorientation, and potentially loss of consciousness. (3) Pulse character: heat exhaustion produces a rapid, weak pulse; heat stroke produces a rapid, strong pulse. Heat stroke is an emergency because thermoregulation has failed and body core temperature is rising unchecked, causing progressive cellular damage to the brain, kidneys, and other organs within a window of minutes to hours. Heat exhaustion is dangerous but the body is still compensating; rest and rehydration usually resolve it.

- Immediate response: go to the neighbor's home in person within twenty-four hours, introduce yourself properly, and acknowledge the problem. Do not dispute whether the bees are yours. Practical steps over the following month: within the first few days, establish a reliable water source at your property — a container with landing surfaces such as corks, gravel, or a wooden float — placed closer to your hives than the pool and filled continuously. Understand that bees habituated to the pool will not shift immediately; give it two to four weeks of consistent availability. Check your property layout: orient hives so flyways direct bees upward before crossing the property line. Suggest a pool cover to the neighbor as an interim measure. Return to update the neighbor on your progress. Bring honey. If the situation does not improve within a reasonable period, consider whether relocating some colonies to an out-apiary resolves the problem permanently.

- On a mild fall day, the two primary hazards of working alone — anaphylaxis and heat stroke — are both reduced: ambient temperature is not generating heat illness risk, and a fall in mild temperatures while wearing full gear is survivable and recoverable. In summer heat, anaphylaxis and heat stroke can both produce incapacitation too fast for self-rescue: an anaphylactic collapse or a heat-stroke-induced confusion event in a remote yard in August means the beekeeper cannot call for help effectively and may not be found in time. Specific scenarios: (1) a beekeeper alone in an out-apiary has an anaphylactic reaction, injects epinephrine, but becomes hypotensive before she can reach her phone or vehicle — no one knows to look for her for four hours; (2) a beekeeper alone in a hot back yard develops heat stroke, becomes confused and disoriented, lies down in the shade, and does not call for help because she believes she is just tired — core temperature continues to rise.

- Accurate two-minute response: Honey bees as a species are not going extinct, and the claim that they are is a misreading of the situation. What is true is that beekeepers in the United States lose a very high percentage of their colonies every year — nearly forty percent last year, and more in previous years — and that sustaining those numbers takes significant work and

expense. The primary driver is a parasitic mite called Varroa that transmits viruses and weakens colonies, and resistance to some treatments is now widespread. Beekeepers replace lost colonies by splitting healthy ones, which is why the total number of managed colonies has held roughly steady. The genuine concern about wild pollinators is a separate and real issue: native bee species — bumble bees, sweat bees, mason bees, and hundreds of others — do face habitat loss, pesticide exposure, and population declines, and those species cannot be commercially managed or replaced. That is a conservation concern worth taking seriously. The best things the public can do: support pesticide-free habitat, plant native flowers, and tolerate wild nesting bees near their homes.

- Wet fuel produces smoke that is hotter and denser rather than cool and white, reducing the calming effect and potentially driving bees off combs. More seriously, synthetic materials — painted wood, treated lumber, foam, plastic — produce combustion byproducts including potentially toxic volatile organic compounds. These can harm the beekeeper by inhalation, harm the bees directly, and leave chemical residues in hive products including honey and wax. The smoker is in direct contact with the hive environment; what burns in it becomes part of that environment. The label standard of "dry natural fuel" is not a preference but a safety and product quality requirement.

- Guidance: gloves are not required in all circumstances, and the choice involves real trade-offs. Leather gloves protect well but reduce dexterity enough that more bees may be crushed during manipulation, releasing alarm pheromone. Thin nitrile or rubber gloves offer better dexterity with some protection. Working gloveless is appropriate for known gentle colonies in favorable conditions, and many experienced beekeepers do so. For unfamiliar colonies, defensive stock, working in teaching or public-facing contexts, or in any situation where a hand sting would be medically significant (known LLR history, blood thinners, etc.), gloves are the correct choice. The veil is the non-negotiable item; gloves are a judgment. Advise the student to start with nitrile or thin rubber gloves, learn to work smoothly, and make her own assessment as she gains experience with her specific colonies.

- Warning signs of escalating defensiveness: guard bees that follow you as you approach the hive before you have opened it, particularly at distances of several meters; bees repeatedly head-butting the veil without landing; a defensive buzz that begins immediately on the first puff of smoke rather than abating; multiple bees patrolling at face level. Escalation indicators once open: bees rolling off the comb surface in quantity; pinging off the veil repeatedly; an intensifying defensive hum. What to do: apply smoke to the entrance and under the cover, work steadily and without sudden movements, minimize crushing. If the colony escalates despite these measures — stings accumulate, bees are unmanageable — close the hive without forcing the inspection. Leave the area. Return on a different day or time when conditions (temperature, humidity, time of day) are more favorable. A colony that is routinely unworkable despite good technique and conditions warrants requeening.

19.19 Further Reading

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Chapter 20. Applied Scenarios & Case Studies

Covers exam questions Q341-Q365.

20.1 Orientation

Every preceding chapter of this guide has developed a domain: Varroa biology, disease identification, honey chemistry, queen genetics, regulatory compliance. Those domains are not separate on the day you open a hive. A spotty brood pattern is simultaneously a disease question, a Varroa question, a queen question, and a management question, and the only thing that separates an experienced beekeeper from an expert is what happens in the pause between opening the lid and reaching for a tool. The expert runs a differential. The competent beekeeper reaches for the most likely explanation. At the master level, the exam is testing which one you are.

This chapter does not repeat what earlier chapters covered. It teaches the reasoning structures that connect them. Six frameworks organize the material: how to read a hive systematically so that findings accumulate into a diagnosis rather than a first impression; how to run a differential when a presentation has more than one plausible cause; how to do the arithmetic of splitting and combining; how the southeastern US climate shapes every timing decision a beekeeper makes; how to decide when a colony's resources are better deployed elsewhere; and what a beekeeper owes the craft, the community, and the regulatory system. Those frameworks are what the scenarios in this chapter – and in the exam – demand.

The central habit the exam is looking for appears most plainly in item Q364, a true/false statement the exam makes about itself: the correct answers to these scenarios depended less on recalling a single fact than on identifying which additional observation would distinguish among competing explanations before acting. That is not a platitude. It is a description of how competent veterinary diagnosis works, how good agronomists work, and how beekeeping at master level works. You will find throughout this chapter that the right first move is almost always one more look, not the treatment drawer.

20.2 Framework 1: Reading a Hive as a Diagnostic Sequence

A systematic inspection runs from outside to inside and from general to specific. Working in that order prevents you from disturbing the very colony you are trying to read, and it means the early observations inform how you interpret the later ones.

20.2.1 Entrance Observation

Stand in front of the hive for sixty seconds before lifting the cover. What you see tells you more than most beekeepers extract from it. Traffic level relative to ambient temperature and time of day tells you whether the foraging force is proportionate to hive population. Dead bees on the landing board and in front of the hive should be examined: deformed wings on corpses identify Varroa-mediated mortality specifically; intact adults in a pile in cold weather may indicate a die-off from confinement; chewed cappings or wax flecks on the ground identify robbing in progress. Guard bees at the entrance are a sign

of an intact defensive force; their absence in a colony that should be strong tells you something about population. Pollen loads coming in tell you the colony is rearing brood.

Robbing deserves its own attention. The flight pattern of robbing bees differs from foragers: they search along the hive body, probe the cracks and joints, dart and hover rather than fly directly in, and fight at the entrance. Wax flecks are torn from cappings as robbers rip into the combs. Orientation flights, which concern some new beekeepers, show young bees facing the hive, hovering and rising in arcs, without fighting and belonging exclusively to that colony. Once you see the difference you will never confuse them. During the midsummer dearth, when robbing is most likely, the beekeeper who pauses at the entrance for sixty seconds identifies the problem before lifting the cover and making it worse.

20.2.2 Adult Bees Inside the Hive

Frame coverage – the ratio of bees to comb surface – tells you population relative to space. A colony should cover most frames it occupies. Bees packed tightly on too few frames, overflowing cells, primed queen cells on the lower bars of congested brood comb: this is the picture of swarm preparation. The appropriate response to that picture is not the same as the appropriate response to a swarm that has already left, and the most important diagnostic step in that situation is establishing which one you are actually facing.

In a queenright colony approaching a swarm, you will find the original queen, her marking intact, eggs and brood in normal pattern, and queen cells in preparation but not yet opened or emerged. In a colony that has already swarmed, the original marked queen is often gone, cells may be open (a virgin has emerged), and the brood pattern will show a gap where the queen interrupted laying before departure. These two situations require completely different interventions: pre-swarm calls for an artificial swarm, a Demaree manipulation, or removal of queen cells along with a split; post-swarm calls for reducing cells to one or introducing a mated queen and letting the colony recover on its own timeline. A beekeeper who takes the pre-swarm action in a post-swarm colony has compounded the problem by adding disruption to a colony already recovering.

20.2.3 Brood Condition

Examine brood systematically: cappings appearance first, then pattern, then the brood itself. Sunken, perforated, or greasy cappings require a matchstick probe; ropiness (the strand that stretches an inch or more from a discolored larva before breaking) is the single most reliable field sign of American foulbrood. Smell: a well-established AFB case often has a foul, glue-pot odor, but odor is absent in many early or light cases and is a prompt to look harder, never a diagnosis. Twisted, yellowish to brown, melted-looking larvae dying in open cells before capping, often with a sour odor and little or no ropiness, suggest European foulbrood. Larvae stretched on their backs in capped or uncapped cells, the head end raised and darkened, lifting out whole as a fluid-filled sac and drying to a brittle, easily removed boat-shaped scale, suggest sacbrood. White or gray granular mummies in the cells or at the entrance are chalkbrood. Discolored capped brood with mite feces visible as white deposits inside vacated cells points toward Varroa.

Pattern tells you about the queen: a scattered pattern with healthy-looking individual larvae and normally placed eggs points first to mites (count them), then to inbreeding (diploid drone larvae removed within hours of hatching); hygienic removal of diseased or mite-infested brood contributes where there is pressure to remove. A sharply bounded area of dead brood along the cluster edge following a cold snap points to chilling. Dead brood concentrated on outer combs facing the sun on a hot day points to overheating. The pattern encodes the mechanism when you know how to read it.

20.2.4 Queen Signs, Stores, and the Whole Picture

Eggs – single, centered in the cell, pointing straight up to slightly angled at the bottom – are the freshest evidence the queen is functioning. Their presence means the queen was laying within the past three days; their absence is not definitive, but it is the first fact you add to your differential. Count frames of bees against frames of brood to assess colony proportion. Stores should be present above and flanking the brood nest, within the cluster's reach. Honey at the outer walls of a box with a small cluster is not stores the cluster can access: the cluster cannot cross cold frames to reach it, and isolation starvation is what that situation becomes in winter.

No single finding is diagnostic. Spotty brood means something different in a colony with deformed-wing adults and mite feces in cells than it does in a colony whose adult population is healthy and whose spotty pattern tracks the cluster edge. The diagnosis is the pattern, not the finding.

20.3 Framework 2: Differential Diagnosis for Common Presentations

20.3.1 Brood Mortality: Scattered, Mixed-Stage

The important differentials for a scattered brood mortality pattern are Varroa-mediated viral damage, hygienic behavior, pesticide kill, and chalkbrood. They are separated by attending to what else is present.

In Varroa-mediated mortality with deformed wing virus, the classic picture is spotty pattern, deformed-wing adults crawling at the entrance, mite feces in cells, and an elevated mite count on a quantitative wash. The count is the decisive step, and it should never be skipped. An impression that mite levels are elevated is not a count. The appropriate wash samples approximately 300 nurse bees from a brood frame – not foragers – expresses the result as a percentage, and compares it against the thresholds appropriate to the season. During the late summer in the southeastern US, even a count of 2 percent requires action, because the bees being reared at that moment are the winter cluster.

Before reaching that conclusion, though, the serious alternatives must be excluded. Sunken, perforated, greasy cappings and a ropy probe exclude American foulbrood first – not because it is the most likely explanation, but because the consequences of missing it are the worst possible. Odor, capping appearance, and the probe together either exclude AFB confidently or require notification of the state apiary inspector. That step costs thirty seconds. Missing it costs the apiary.

Hygienic behavior produces a spotty pattern because bees remove diseased or parasitized larvae before capping or shortly after, leaving empty cells distributed throughout the brood. The pattern tends to concentrate around areas of disease or mite pressure and improves as the affected cohort passes.

Pesticide kill tends to be sudden in onset, affects a specific developmental stage (the stage that was exposed), and may coincide temporally with a nearby spray event.

20.3.2 Brood Mortality: Sharply Bounded

When dead brood occupies a precise geometric area rather than a scattered pattern, the pattern itself tells you about the cause. Chilling follows the cluster's edge closely: the colony abandoned that comb during a cold spell, and the brood at the outer margin died. You will find healthy brood at the center. This is a management finding – the colony was too small for the space it occupied, or a cold snap exceeded the cluster's thermal capacity – rather than an infectious disease finding. Sunburn follows the exposure pattern of outer combs facing the sun during extreme heat. Neither condition is infectious, but both tell you something actionable about space management and colony population.

20.3.3 Adult Population Decline With Healthy Brood

When the adult population falls but the brood looks normal and is present in good quantity, the differential narrows to losses of the adult cohort rather than brood production failure. Pesticide forager kill is sudden: the foraging force fails to return one afternoon, the hive falls quiet, and the remaining nurse bees are temporarily adequate to cover the brood. Drift losses are chronic and directional – bees from colonies downwind or at row ends drift persistently to their neighbors. A chronic, progressive loss of adults with dysentery signs, increased mortality at the entrance, and abbreviated brood-rearing activity points toward intestinal pathogen involvement, particularly in the context of an established *Vairimorpha (Nosema) ceranae* load. Queen failure eventually produces adult decline as the brood rearing rate drops, but the brood is the first thing to show it – eggs and young larvae disappear before adult population falls.

20.3.4 Elevated Mite Count Despite Recent Treatment

A mite count that fails to fall after a properly applied treatment identifies one of three situations: application error, resistance, or reinvasion from outside. The distinction between them requires the timing of the post-treatment count. A count taken immediately at strip removal – for a product using strips – reflects the product's performance over the whole application period: an effective strip kills immigrating mites as well as resident ones, so a count that has not fallen is not explained by reinvasion after treatment. That leaves application error and resistance as the explanations to distinguish.

Application error is more common than resistance and should be reviewed first. Was the dose correct for the colony size? Were strips placed within the cluster's patrol zone? Was the product stored and applied within its labeled temperature range? Was the application duration complete? Was the product fresh and not degraded? Formic acid products have a labeled temperature ceiling for a reason: at high temperatures, vapor concentration exceeds the label rate, brood mortality and queen loss become serious risks, and applying formic at 95 degrees F when the label ceiling is 85 degrees F is both unlawful and counterproductive. The label is not advisory. It is the legal basis for use.

If application was sound and the count still did not respond, the next step is to switch every colony above threshold to a product of a different mode of action and verify with a post-treatment count. A treatment that fails while an alternative succeeds points to resistance, which can be confirmed with a

field amitraz-resistance assay on mites from the failing colonies or by asking the state apiarist or a university lab to test them. This is no longer an edge case. A 2026 study screening mites from colonies that had lost heavily despite amitraz treatment found the Y215H mutation in the octopamine receptor gene – the mutation conferring amitraz resistance – in 100 percent of the 39 mites screened from 18 colonies in five commercial operations, and a regional survey cited in the same paper found it in about two-thirds of mites. Those operations were sampled because they had suffered heavy losses, so the figure shows that resistance is widespread and serious rather than giving a baseline prevalence. Post-treatment verification is not an optional quality check; it is the mechanism that catches a failing treatment before the colony's winter bees are produced under uncontrolled mite pressure.

20.3.5 Failed Queen Introduction

A queen found dead in her cage after introduction with queen cells present on the comb is not a mystery. A colony that retained brood young enough to raise its own queen when it was made queenless will start cells, and any introduced queen competing with a viable cell or an unnoticed virgin will be rejected and killed. The failure was procedural: the colony was not genuinely queenless at introduction, or queen cells were not removed at introduction and checked again about a week later. Reintroducing a new queen without addressing this situation exactly repeats the failure. The remedy is to check again for cells and virgins, remove every cell found, wait for any remaining virgin to be discovered and removed, and then reintroduce with a candy-plug cage that gives the colony additional time to accept the queen's pheromones before she is released.

20.3.6 Failing Queen Versus Laying Workers

A queen producing drone brood in worker-sized cells but still visible and laying single, centered eggs presents differently from a laying-worker colony, and the distinction matters because the remedies are incompatible. A failing queen – one whose stored sperm supply is depleted or whose viability has diminished with age or thermal damage during shipping – places eggs singly, centered in the cell, as a queen always does. The dome-capped drone brood in worker cells is her signature. The colony has not been queenless long enough to develop the chaotic egg-laying of workers. Finding the queen, removing her, and introducing a mated replacement solves the problem.

Laying workers arise only after the colony has been queenless long enough for ovary development among the workforce – typically three or more weeks. The eggs from workers are scattered, multiple per cell, and placed on the walls of cells rather than at the center of the base. No queen will be found. A colony in the laying-worker state resists queen introduction because the laying workers produce pheromones that suppress queen acceptance, and the colony no longer behaves like a queenless colony waiting for a queen. Combining the laying-worker colony with a strong queenright colony is the standard management; shaking its bees out in front of the queenright colony is more reliable than a straight newspaper combine (see When Not to Combine, below).

20.3.7 Diagnosing a Package That Has Not Developed

A package installed three weeks ago with no eggs, no larvae, and no capped brood presents two concurrent problems: the queen is lost or failing, and the colony has probably been underfed. The

absence of queen cells is informative – a queenless colony with viable eggs and larvae produces emergency cells within days, so no cells alongside no brood means the queen never laid or laid so briefly that the cells were never started. A test frame of eggs and young larvae from a healthy colony, introduced without its nurse bees if possible, confirms queenlessness in three to four days if cells appear. Meanwhile, continuous feeding with a one-to-one syrup is essential: two frames of drawn comb in three weeks is low for a package; check the feeding record, because inadequate syrup is a common cause, although a package with no laying queen and no young bees also draws comb slowly. Bees cannot secrete wax and draw comb without a surplus of incoming sugar or a nectar flow. Address both problems together or the queen, once introduced, has no comb to lay in.

20.4 Framework 3: The Arithmetic of Splitting and Combining

Every decision to split or combine a colony is a resource allocation decision, and doing the math badly in the field has consequences that persist through the winter.

20.4.1 Combining: Conditions and Method

The rule before combining is identical to the rule for purchasing equipment: verify the colony's disease status before allowing it to share resources with a sound one. Combining a colony with American foulbrood into a clean one has produced apiary-wide outbreaks that could have been avoided by a five-minute assessment. The newspaper method is not optional sentiment: the gradual barrier gives both colonies two to three days to develop a combined scent profile while workers chew through the paper. By the time bees from the two colonies meet directly, the pheromonal differences have diminished enough that fighting is minimal. Without the paper, the immediate mixing of two foreign colonies produces fighting intense enough to kill the queen.

The decision to combine should be made by asking whether either colony would survive winter as a single unit. If the answer for both is no – because population is too small, because the season is too late to build, or because both lack the critical mass to defend against small hive beetle – combining them is not merely a convenient option. It is the correct management, and the resources of both colonies are preserved rather than lost. Two four-frame colonies in early autumn that are otherwise healthy, mite-free, and have adequate stores are better managed as a single eight-frame unit than as two separate units that may not each maintain enough warmth or defensive force through a southeastern winter. An alternative that keeps both queens is to winter them as a double nucleus - side by side in one box, separated by a solid divider, with separate entrances - so that they share warmth through the partition. Adding a second brood box to either to give them room to move is the wrong response: it increases the volume each small cluster must maintain and creates undefended space above them for small hive beetle to exploit.

20.4.2 When Not to Combine

A colony infected with American foulbrood is never combined with a sound colony. If the diagnosis is confirmed or strongly suspected, containment is the priority, and the potential loss of the sound colony's resources is not a reason to combine. Similarly, combining a laying-worker colony into a queenright colony requires management beyond the simple newspaper method: the workers defending

their colony may kill the receiving colony's queen, and the usual approach is to give the queenright colony's bees an extended mixing period or to shake the laying-worker colony's bees out at a distance from the apiary and let them drift on their own. The newspaper method was designed for two colonies that each have or recently had a queen; it does not reliably solve the laying-worker situation.

20.4.3 Splits: Does the Mother Colony Have the Resources?

A split removes bees, brood, and stores from the mother colony and expects both halves to be viable units. The minimum calculation before splitting is whether each resulting half can maintain its own temperature, defend its own entrance against beetles and robbers, rear its own queen (in the half that keeps no queen), and build adequate population for the remaining season. A colony that is just strong enough to manage small hive beetle pressure under the current population produces two halves that are not strong enough. Both fail. A colony that has reached or exceeded two full brood boxes of bees and brood in late spring has resources to split without depleting either half to the point of failure. Timing relative to the local forage calendar matters: a split made in time for the virgin queen to complete her mating flights and begin laying before the dearth arrives has the summer to build. A split made during the dearth has no margin.

20.5 Framework 4: Seasonal Management Under Southern Conditions

The southeastern US does not behave like the regions where most beekeeping literature was written. The differences are not edge cases; they are the central facts of management in this region.

20.5.1 The Long Brood Season and Its Varroa Consequence

Brood rearing in the coastal plain and piedmont rarely stops for more than a few weeks in the year, and some locations in Gulf coastal areas see near-continuous brood year-round. Varroa reproduces exclusively in capped brood. More brood cycles per year means more Varroa generations per year, which means a mite population compounds faster in this region than in northern apiaries. A colony that reaches spring with a mite population of 1 percent reaches late summer with a far heavier load than the same starting population managed under a region with a reliable broodless period. Mite management cannot be deferred in the southeastern US. The beekeeper who waits for visible signs of Varroa damage before treating has already lost the window.

The absence of a reliable broodless period also complicates oxalic acid application. A single dribble treatment works when the colony is broodless or nearly so, because oxalic acid does not penetrate cappings. In a region where brood may be present continuously, a single winter dribble reaches only the mites on adult bees. Extended-release glycerin-impregnated oxalic acid strips, such as VarroxSan (EPA Reg. No. 94413-3, registered in the US in December 2023), address this by maintaining active ingredient in the hive across a label period of 42 to 56 days, which spans two or more 21-day worker brood cycles. Field trials found effective mite reduction with these strips in fall and early summer applications with no significant oxalic acid residues in honey.

20.5.2 The Late-Summer Window: The Most Important Timing Decision of the Year

The winter bees that will carry the colony through January and February are reared from late August into October throughout most of the southeastern US, which is why the decisive count and treatment come in late July and August. A colony with elevated mite loads in that window produces a winter workforce that was parasitized during larval and pupal development. Those bees emerge with shortened lifespans and immune compromise from deformed wing virus. As winter progresses, they die faster than they would otherwise. The cluster dwindles. Eventually it reaches a size too small to bridge to its remaining honey stores, and the beekeeper finds in late winter a cluster of dead bees, heads in cells, with abundant honey on the outer frames. This is isolation starvation. The proximate cause is that the cluster could not reach its food. The underlying cause is mite damage to the autumn bee cohort, months earlier.

A beekeeper who responds to this finding by adding more feed the following autumn has addressed the proximate cause and left the underlying one untouched. The correct response is to understand the chain: mite load in late summer predicts autumn bee quality, which predicts winter cluster viability. The management change is to complete the decisive mite treatment in late summer – before the winter bees are being reared – verify it worked with a post-treatment count, and repeat as needed. That single timing insight separates beekeepers who lose colonies every winter from those who winter through reliably.

20.5.3 Dearth Management

The summer dearth – typically July through August in much of the southeastern US, though the timing varies by elevation and coastal influence – alters the colony's relationship to everything around it. Incoming nectar stops or slows sharply. The colony becomes more defensive. Robbing begins when one colony detects exposed honey or a weakened neighbor. Small hive beetle populations, unchecked by the colony's foraging activity and now facing a colony with a smaller defensive force, expand into any unguarded space.

The beekeeper's response to the dearth should begin before it arrives, not during it. Entrances should be reduced to a width the bee force can actually defend. Exposed feed, drips from leaking equipment, and empty supers left on the apiary can all trigger a robbing event that, once begun, accelerates through positive feedback: robbing bees from a successful raid return and recruit more, and a colony that is being robbed goes into a defensive state that excludes its own foragers and prevents them from returning with whatever forage remains available. The entrance is the fulcrum. The beekeeper who moves to reduce it when they see wax flecks on the landing board and searching bees on the hive exterior has waited too long, but acting immediately can still stop the cascade. Opening the hive to assess while it is being robbed makes the situation worse – it exposes comb and the interior to the robbers and prevents the guards from concentrating at the entrance.

Feeding during a dearth requires attention to the robbing risk. Open feeders, top feeders with loose lids, and communal trays in the apiary are all robbing triggers. Internal feeders that confine feed within the

hive body are safer. Feeding may not be warranted at all if stores are adequate; a thorough heft of each hive gives you a weight estimate before you decide.

20.5.4 The Late-Season Checklist

By the first cool nights of autumn, a beekeeper should be able to answer affirmatively to five questions for each colony. Does it have adequate stores? Is it queenright, with a queen young enough to carry it through and build population in spring? Is the mite load below threshold, confirmed by a recent count rather than assumed from a previous one? Is there no active disease? And does it have a population sufficient to defend its own space against small hive beetle and robbers? A colony that fails any of these five conditions going into autumn is a colony that will not winter successfully without intervention. Identifying the gap tells you what the intervention is.

20.5.5 Varietal Honey Production

Producing a varietal honey from a specific bloom requires reverse-engineering the season to protect the crop's identity before a drop of it is collected. The single most important step is clearing all previous honey from the supers before the target bloom begins. Anything already in the comb is extracted alongside the varietal and dilutes its character. Cleared supers – drawn comb that has been extracted, ripened, and confirmed free of honey from earlier flows – go on the colony immediately before or at the opening of the bloom. They come off when the bloom ends, before the bees incorporate subsequent forage. The crop is kept segregated through every handling step: extraction, settling, storage, and bottling in a labeled lot. Under the FDA's 2018 final guidance on honey labeling, a floral name is appropriate only when the labeler has information supporting that the named plant is the chief floral source; a blend in which it is not the chief source should not carry that name.

20.5.6 Designing a First Season in the Southeastern US

A first-year beekeeper in the southeastern US benefits from having checkpoints attached to reasons rather than calendar dates, because the season's events vary by elevation, coastal proximity, and local forage patterns. In late winter, the first warm day above 55 degrees F for hive inspection reveals whether the queen is laying, whether stores are adequate (feed if light), and gives a baseline mite count before the spring population expansion begins. In early spring, inspections every seven to ten days catch swarm cells before preparation is complete and allow the beekeeper to practice artificial swarms or splits. Supers go on ahead of the main flow, not during it. When the flow ends, honey is removed promptly, and the most important mite count of the year – the late-summer one – is taken in July or August. The treatment that follows that count protects the winter bees. In early autumn, a post-treatment count verifies that the treatment worked; failing colonies are combined rather than carried; stores are built with heavier syrup while temperatures still allow the bees to ripen it. Through winter, the colony is mostly left alone, but hefting the back of the hive gives a weight estimate without disturbing the cluster, and emergency candy boards or fondant can be placed quickly on colonies that have grown light.

20.6 Framework 5: Recognizing When a Colony Is Not Worth Saving

A master beekeeper's ability to allocate resources – including the decision not to invest them in a colony that cannot be saved – is as important as any technical skill.

20.6.1 The Small Hive Beetle End Point

A colony found with slimed frames, beetle larvae throughout the comb, fermenting honey, and very few adult bees has been overwhelmed. The fermenting honey and beetle frass render the comb uninhabitable and typically unsalvageable. The appropriate response is not to rescue this colony but to contain the damage: remove it from the apiary promptly so it does not become a beetle reservoir and so the fermentation odor does not attract more robbing and beetle activity to neighboring colonies. Any remaining cluster and queen can be shaken onto clean equipment and combined with a strong colony if they are worth the effort, though often they are not. Comb too damaged to salvage is destroyed; boxes, bottom boards, and covers are scraped, washed, and dried thoroughly in sunlight before reuse.

The step that separates a competent response from merely a tidy one is asking what weakened the colony in the first place. Small hive beetles do not overwhelm healthy, populous colonies – they exploit colonies that have already been compromised by queen failure, mite damage, disease, or excess space. The cause that permitted the slime-out is still present in the apiary. That is what requires attention.

20.6.2 Resource Accounting

A colony with a failing queen, a mite load above threshold, and too few bees to cover more than two frames is consuming the beekeeper's time, medication, and introductions against very poor odds. Treating the mites will not save a colony the queen cannot populate. Introducing a new queen will not save a colony being destroyed by viral load from the mites. And each resource spent on a colony that does not survive is a resource not spent on a strong colony that could have been split or made into a pollination unit.

The compassionate but clear decision is to combine whatever healthy bees and viable brood exist from the weak colony into a sound one using the newspaper method, after first verifying there is no disease in either colony. The combined colony gains bees and the weak colony's bees gain a functional queen, adequate population, and a disease-free environment. Both components are better served than they would have been by carrying the failing colony forward independently.

20.6.3 When Destruction Is Correct

American foulbrood requires destruction of comb and often equipment, and no amount of reluctance changes that conclusion. Oxytetracycline and other antibiotics suppress the vegetative stage of *Paenibacillus larvae* and suppress clinical signs, but they do not kill spores. A colony treated with antibiotics may look healthy while carrying a spore load that contaminates the comb, the honey, and everything that contacts it. This is why antibiotics mask rather than cure AFB, and why burning or irradiation (for the wood equipment) remains the standard in most jurisdictions. The legal framework changed on 1 January 2017: antibiotics for honey bees now require veterinary oversight – a Veterinary Feed Directive for in-feed products or a prescription for water-soluble ones – which in practice means a diagnosis is required before treatment is available. That pressure toward confirmed diagnosis rather

than empirical treatment is appropriate, because the correct diagnosis for confirmed AFB is not an antibiotic order: it is a call to the state apiary inspector.

A colony that functions as a mite bomb – consistently high counts, confirmed amitraz resistance, located where its mites will wash into neighboring colonies through drifting and robbing – represents a threat to the entire apiary. Treating it aggressively with an alternative mode of action is the first response. If that fails and the colony cannot be brought to threshold, the calculus of whether to continue investing in it must account for the damage it is inflicting on colonies that could otherwise be managed successfully.

20.7 Framework 6: The Beekeeper's Obligations

20.7.1 Record-Keeping

Records are the difference between post-mortem and investigation. A colony that dies in January is a mystery without data and a case study with it. The minimum useful record for each colony captures queen identity and age, mite count dates and results, treatment applied (product, dose, date, duration), treatment outcome (post-treatment count result), inspection findings noting any disease signs, population assessment, and stores estimate. When six colonies in an eighteen-colony apiary die in winter with mite counts excluded as the cause, having records from those six tells you whether they shared a queen source, a position in the apiary, a feeding history, or an autumn population estimate. Without records, six colonies are six mysteries. With records, they may tell you something you can act on.

Lot-coding honey is the same principle applied to the extracting room. A fermentation event in one lot can be isolated, recalled, and managed proportionately when lot codes track which supers contributed to which tank. Without lot codes, one bad tank calls the entire season's crop into question and offers no way to identify who received product from that tank. The lot code is not a regulatory flourish; it is what makes the response proportionate.

20.7.2 Regulatory Obligations

The AFB protocol requires more than competent management. It requires that the state apiary inspector be notified promptly when the disease is suspected, that the beekeeper submit a comb sample as directed, that the hive not be disturbed in ways that spread spores (frames, bees, and equipment confined to that location), and that the entrance be reduced or closed against robbing. The interval between suspicion and confirmation is when most apiary-wide outbreaks are created. Each of those is entirely within the beekeeper's control. What must not be done is equally clear: frames, bees, honey, and equipment must not move to other colonies; honey from the suspect colony must not be extracted or sold; and antibiotics must not be applied without a veterinary diagnosis, and even with one, they do not resolve the spore contamination problem.

The pesticide label is a federal document, not a suggestion. An applicator who exceeds the labeled dose because they believe it will compensate for resistance has committed a violation and, very likely, caused harm. A label temperature ceiling exists because the chemistry and the biology behind it were studied and a limit was determined. Operating outside those limits produces outcomes the label was designed

to prevent. For the beekeeper, this means reading the pesticide label as a binding document and treating its terms – temperature range, application rate, restriction on use with supers – as the actual governing constraint.

20.7.3 Community Obligations

A swarm call from a neighbor is not an inconvenience; it is the most common point of contact between the craft and the public, and how it is handled shapes public perception of beekeeping in that neighborhood for years. A swarm on a low branch is typically docile, as clustered swarms nearly always are, and it can be captured without incident with a hive box, a frame or two of drawn comb, and appropriate protective equipment. The period of isolation that follows – keeping the captured swarm separate from the established apiary while monitoring for disease and temperament – is not optional caution. A swarm of unknown origin may carry diseases or mite loads that you do not want in your apiary. In areas where African-derived genetics are present in feral populations, temperament assessment after the new queen's workers have replaced the swarm's initial cohort is a matter of public safety as well as management preference. Requeening with known gentle stock eliminates the genetic uncertainty.

The neighbor who does not monitor or treat for Varroa is a community-level problem. But approaching that neighbor as a community problem begins with your own data: documented pre- and post-treatment counts that show your treatment worked, followed by serial counts through the autumn that show when and how fast mite numbers rise afterward. A distance gradient in reinvasion rate across your apiary, or a comparison with an apiary further from that neighbor, provides the evidence you need to support a conversation based on data rather than accusation. The conversation begins cooperatively, with shared data and an offer to help with monitoring. A local association or the state apiary inspector can provide education support, and if the neighbor's colonies are actively collapsing and spreading disease, regulatory options may exist. But the data come first, and the tone is collaborative.

A grower asking for advice about spraying a crop adjacent to an apiary provides an opportunity that is more useful than a complaint filed after a kill event. The most protective set of practices – following pollinator label statements, applying at night, choosing lower-toxicity registered options, avoiding spray drift onto margins and water, disclosing the full tank mix, and providing advance notice – are not individually obvious to a grower who does not work around bees. The tank mix disclosure is worth requesting specifically: some fungicides substantially increase insecticide toxicity to bees even when neither product alone is acutely harmful. Advance notice matters because moving colonies is far safer than confining them in regional heat, where a sealed hive can overheat within hours.

20.7.4 Teaching and the Handling of Confident Mistakes

A master beekeeper is frequently the most experienced person in the room and is expected to teach. How a knowledgeable beekeeper handles a confident but mistaken statement from a student is itself a competency that the exam is testing. The substantive point about any specific factual claim – say, that screened bottom boards eliminate the need for Varroa treatment – is that controlled trials in the early 2000s found screened boards increased natural mite fall and provided useful monitoring but produced at most small reductions in colony mite populations, not control. Screened boards are genuinely useful

for monitoring and ventilation; they simply do not control mites at a level that prevents colony damage. A student who has encountered this belief as widely repeated has heard something plausible: mites do fall through a screened board and cannot return. The mechanism sounds right. But a plausible mechanism and a tested outcome are different things, and teaching that distinction – pointing to the controlled trials, offering the references, explaining what screened boards are actually useful for – is more valuable than either confirming the belief or dismissing it without basis. The manner of correction determines whether the correction is accepted.

The final habit the exam identifies as distinguishing a capable beekeeper in the southeastern US from one who has read widely but managed little is the willingness to say plainly when they are not sure. Knowledge of the limits of your knowledge is itself expert knowledge. A master beekeeper who refers a beekeeper to the state apiary inspector, the local Extension service, or a peer with specific expertise rather than improvising past their own certainty is demonstrating exactly the intellectual honesty the credential is supposed to stand for.

Taken together, the habits that separate a capable beekeeper in the southeastern US from one who has read widely but managed little come to six. Measure rather than assume: mite counts, hive weights and written records. Work from the local calendar of flows and dearths rather than a book written for another region. Diagnose before acting, excluding the serious possibilities before settling on the convenient one. Read labels as binding, record what was applied and verify that it worked. Anticipate the region's big problems - swarming, robbing, small hive beetle and mites - because each is cheaper to prevent than to fix. And know the limits of your knowledge: consult the inspector, Extension and the local association, and say plainly when you are not sure.

20.8 Numbers to Know Cold

Figure	Value	Why it is that value
Mite action threshold, spring	1% (1 per 100 bees), HBHC 9th ed.	Spring colonies are building rapidly; a mite load even at this level will compound for months
Mite action threshold, late summer/autumn	2% (2 per 100 bees)	Winter bees are being reared; acting at once protects the cohort that must survive months without replenishment
Alcohol wash sample size	~300 nurse bees from a brood frame	Nurse bees carry the highest mite burden; 300 gives a count precise enough to be actionable
Result expression	Mites per 100 bees (percent)	Normalizes for sample variation; 9 mites in 300 bees = 3%
Post-treatment count timing	Immediately at strip removal (for strip products)	Reflects performance over the whole application period; a poor result points to treatment failure rather than reinvasion after treatment
AFB ropiness length	~1 inch	Defines a positive result on the matchstick or probe test

Figure	Value	Why it is that value
Honey moisture threshold for fermentation risk	~17-17.5% (risk rises steeply above ~18-19%)	Below about 17% fermentation is essentially impossible; between about 17.5% and 19% the risk depends on yeast count and storage temperature
Winter bee production window	Late August into October in most of the southeastern US; the treatment decision comes in late July-August	Bees reared then become the winter cluster; mite loads at that time directly predict winter survival
Colony losses nationally, 2024-25	55.6% – the highest recorded	Contextualizes the management challenge; replacement by splits is why colony numbers hold
Colony losses nationally, 2025-26	39.9% (preliminary)	Still roughly double the 15-20% beekeepers describe as acceptable
Amitraz resistance mutation (2026 study)	Y215H found in all 39 mites screened from 18 colonies in five operations with heavy losses; about two-thirds of mites in a regional survey	Post-treatment verification is now essential, not optional, in any operation using amitraz
ABPV prevalence in 2026 study	72% of screened colonies	Underscores the viral load carried alongside mite infestations
DWV-B in symptomatic bees (2026 study)	100%	Specific association between this variant and colony collapse presentations
VFD requirement for antibiotics	Since 1 January 2017	Oxytetracycline, tylosin, lincomycin require veterinary oversight; OTC purchase is no longer lawful
Extended-release OA strip duration	42-56 days (label range)	Spans two or more 21-day worker brood cycles, unlike a single dribble that reaches only adult-phase mites
OA registered products	Api-Bioxal, Api-Bioxal RTU, EZ-OX, VarroxSan	VarroxSan is the only extended-release strip registered in the US (HBHC 9th edition, 2026)
HBHC Tools for Varroa Management edition	9th edition, released 22 June 2026	Current citation for all treatment guidance and threshold discussions
Temperament change after requeening	About 6 weeks	Time required for the new queen's workers to replace the original workforce
Package comb drawing, normal	Well more than 2 frames in 3 weeks	Two frames in three weeks on a package is low; check feeding and the queen, and address both together
Queen introduction cells check	At introduction AND again ~7 days later	Cells missed at introduction hatch and reject the introduced queen
Master beekeeper exam window	All four components within 5 consecutive years	Individual sections may be retaken; no single-section extension

20.9 Common Misconceptions

Misconception: Screened bottom boards control Varroa well enough that treatment is not necessary. **Correction:** Screened boards increase natural mite fall and are valuable for monitoring and for some ventilation benefit, but controlled trials found they do not produce meaningful reductions in mite population within the colony. Mites that fall through do not return, but mites reproducing in capped brood are not affected. Treatment is not eliminated by the presence of a screened board.

Misconception: If I applied the treatment correctly, the mites are under control. **Correction:** A properly applied treatment is the beginning of the management cycle, not the end. A post-treatment count confirms efficacy. With the amitraz-resistance mutation found in every mite screened from five operations that had suffered heavy losses, a treatment that was effective two seasons ago may not be effective now. The count is the control.

Misconception: A colony with a laying queen will accept an introduced queen. **Correction:** A colony that is queenright, or that has a virgin or queen cells it has started, will reject and kill an introduced queen. The presence of cells is an especially reliable predictor of rejection. Introduction without verifying complete queenlessness and without removing all cells at introduction – and again a week later – repeats this mistake in a high proportion of cases.

Misconception: Spotty brood means foulbrood. **Correction:** Spotty brood is a sign shared by at least a half-dozen conditions, from Varroa-mediated viral damage to hygienic behavior to chilling to chalkbrood to sacbrood to inbreeding to a newly failing queen. It is a starting point for a differential, not a conclusion. The capping appearance, the probe test, the smell, and the distribution pattern together define which diagnosis fits.

Misconception: A weak colony can be built up to full pollination strength in a few days with supplemental feeding. **Correction:** Building colony population requires brood cycles. Each queen can lay about 1,500 to 2,000 eggs per day, and those eggs take 21 days to become workers. Supplemental feeding supports growth but cannot compress the biological timeline. A colony at 5 frames of bees eight days before a pollination event will still be at approximately 5 frames when the bloom opens. Declining or renegotiating a contract rather than delivering substandard colonies is the professional response.

Misconception: Waiting until autumn to treat for Varroa is safe if the colony still looks healthy in midsummer. **Correction:** The colony looks healthy because the damage is invisible: mite infestation of developing brood is not visible on the adult bees. By the time clinical signs appear – deformed wings, spotty brood, declining population – the winter bee cohort is already being produced under mite pressure. Treating in autumn is too late to protect those bees.

Misconception: You can combine a laying-worker colony over newspaper like any other combination. **Correction:** Laying workers produce pheromones that interfere with normal acceptance of a queen, and the laying-worker colony's bees may kill the receiving colony's queen during the newspaper-merging period. The appropriate technique for a laying-worker colony is to shake the bees out at some distance from the apiary or in front of a strong queenright colony so that foragers drift into the queenright colony on their own, or to use the newspaper method with extended vigilance and the understanding that it is less reliable here.

Misconception: A colony that died from isolation starvation just needed more honey in the fall. **Correction:** Isolation starvation is usually the proximate cause of winter death in Varroa-damaged colonies, but the underlying cause is a compromised winter bee cohort that dwindled too fast to bridge to the available stores. Adding honey in autumn does not address shortened bee longevity from viral damage. Mite control in late summer – before the winter bees are reared – does.

Misconception: Honey ferments because it was filtered improperly. **Correction:** Honey ferments because its moisture content is high enough for osmophilic yeasts to grow. Below about 17 percent it is essentially safe; between about 17.5 and 19 percent the risk depends on yeast count and storage temperature; above about 19 percent fermentation is likely. Filtration removes wax particles and other debris but does not change moisture content and does not prevent fermentation. Moisture content is controlled by harvesting only fully capped combs, measuring each tank with a temperature-corrected refractometer, and drying high-moisture honey with moving warm air before bottling.

Misconception: If my mite count was below threshold in August, I do not need to count again before winter. **Correction:** Mite populations can rebound through immigration from collapsing neighboring colonies, particularly in autumn when late-season collapses drive robbing events that redistribute mites rapidly. A colony that was at 1.5 percent in August may be at 4 percent by October. An autumn verification count, separate from the post-treatment count, protects the winter assessment.

Misconception: Applying more amitraz compensates for reduced efficacy from resistance. **Correction:** Amitraz resistance is a receptor-level mutation in the mite. Increasing the dose above the label rate does not overcome a binding-site change and violates federal pesticide law. The response to suspected resistance is a mode-of-action switch and a post-treatment verification count, not a dose increase.

Misconception: A colony that supersedes its queen retains its original temperament. **Correction:** A superseded queen's daughter mates with drones from the local population, which may include feral colonies with unknown genetics. The new workers emerging from that queen's brood will reflect her mating outcomes, which may be more or less defensive than the original stock. An unmarked queen where a marked one was introduced is the diagnostic sign of supersedure or swarming, and it explains an otherwise unexplained temperament change. Requeening with known stock resolves it.

Misconception: Moving a frame of brood from a healthy colony to a weak one is safe if both look fine. **Correction:** Visual inspection does not detect American foulbrood in its early stages, is not sensitive to subclinical levels of several viral pathogens, and does not confirm absence of mite infestation. Transferring frames between colonies can transfer disease or mites in either direction. The movement is only appropriate when the donor colony has been assessed as clean at the level of detail the situation requires.

20.10 Self-Check Questions

- You open a colony in late spring and find the queen laying normally, bees on every frame, and fourteen queen cells along the bottom bars of the two lower brood boxes. Before taking any action, describe the single most important question you must answer and explain what you would look for to answer it.

- In midsummer, a colony shows a spotty brood pattern and adult bees with crumpled wings crawling at the entrance. Describe the diagnostic sequence you would follow, naming every step you would take and the order in which you would take them before concluding and choosing a treatment.

- A colony in late July in the piedmont has a mite count of 3.5 percent. Honey supers are on. Daytime temperatures are averaging 93 degrees F. Describe the reasoning process you use to select a treatment or decide to delay, including the tradeoffs and the governing constraints.

- You find a colony with sunken, greasy-capped cells, a positive ropy-pull result, and an odor consistent with American foulbrood. Write out exactly what you do from the moment you close the hive until the situation is formally resolved. Include what you must not do.

- A beekeeper has two colonies entering autumn: one has four frames of bees, no disease, low mite count, and adequate stores; the second has four frames of bees, no disease, low mite count, and adequate stores. Both are queenright. What is the most defensible management decision, and what is the one condition that is essential to doing it safely?

- Describe the difference in presentation between a failing queen and a laying-worker colony. For each, state the appropriate remedy and explain why the remedy appropriate to one fails for the other.

- A package installed three weeks ago has a released queen, two frames of drawn comb, no eggs, no larvae, and no queen cells. List the two distinct problems this colony presents, describe the diagnostic step that tells you whether a queen problem exists, and explain why both problems must be addressed simultaneously.

- A beekeeper applies amitraz strips per label, leaves them in for the full duration, and measures mite counts immediately at removal. The pre-treatment count was 6 percent; the post-treatment count is 5.5 percent. What are the two most likely explanations, how would you distinguish between them, and what should the beekeeper do next?

- You notice that three colonies on the south end of your apiary are consistently running mite counts double those of the other colonies under identical management. Describe how you would investigate the cause before deciding on a management response.

- You are teaching a beginning beekeeper class. A student asks whether they need to do mite counts if they are using a screened bottom board. Describe what you would say, including the substantive content of the correction and the way you would deliver it.

- A neighbor half a mile away keeps colonies he never treats. Your autumn mite counts are rising sharply even after your own treatments succeeded by post-treatment counts in August. Describe how you would establish whether there is a connection between the two facts and what you would do about it.

- You are planning to produce a varietal sourwood honey from a bloom that occurs from late June into July in the mountains and foothills. Describe the complete management plan from early spring through extraction, identifying the single step that most protects the varietal character of the crop and explaining why.

20.11 Self-Check Answers

- The most important question is whether the colony has already swarmed. The answer tells you whether the intervention is preventive or remedial. You look for whether the original queen (marked, if you have records) is present and still laying; whether any cells have already opened, showing a virgin has emerged; and whether the brood pattern shows a laying gap that would indicate the queen stopped laying briefly before departure. A queenright colony with all cells intact and a continuous brood pattern has not yet swarmed – you have options, and the cells are still workable. A colony missing its original queen with open cells may already have a virgin present, and the intervention is entirely different: reduce to one cell or introduce a mated queen and do not attempt to split the colony until queen status is confirmed.

- The sequence runs from exclusion of serious disease to confirmation of the likely diagnosis. First, examine the brood closely for capping abnormalities: sunken, greasy, or perforated cappings require a matchstick probe and a smell assessment. A ropy pull from a discolored larva or an odor of sweet rot halts the investigation and triggers the AFB protocol. Absent those signs, proceed: look for chalkbrood mummies, sacbrood larvae, and chilled-brood distribution. Confirm the queen is present with single, centered eggs. Then take an alcohol wash of approximately 300 nurse bees from a brood frame – not foragers – and calculate the percentage. Deformed-wing adults, spotty brood, and a count above the late-summer threshold together make the diagnosis. Without the count you have a clinical picture but not a confirmed severity. The response is treatment with a product appropriate to the temperature and super situation, and a post-treatment count to verify efficacy.

- Three-and-a-half percent in late July is above the late-summer threshold of 2 percent, and the summer dearth is often near its peak. The reasoning proceeds through the governing constraints in order. Can the supers stay on? That depends on the product: amitraz, the thymol products, the pyrethroid and coumaphos strips, and Norroa require supers off, while formic acid, the oxalic acid products (including VarroxSan), HopGuard 3, MBG2X5G and OrganiShield are labeled for use with supers on. Can formic acid be applied? Not at 93 degrees F: the Formic Pro label limit is 85 degrees F daytime highs, and exceeding it risks brood mortality and queen loss. A single oxalic acid dribble or vaporization reaches only mites on adult bees, and there is no broodless period in midsummer in this region. The extended-release VarroxSan strip, applied for the label duration (42 to 56 days), is the most defensible choice: it is labeled for use with supers on, provided at least one box separates the treated brood chamber from any honey to be extracted, and works through a brood cycle; HopGuard 3, labeled to 100 degrees F, is the alternative. If the chosen product required supers off, the supers would come off - the remaining crop is secondary to winter bee quality. Apply per label and take the post-treatment count at strip removal.

- Close the hive carefully without moving any frame, bee, or tool to another hive. Work this colony last or clean and disinfect the hive tool and gloves with a flame or bleach before contacting any other equipment. Record the hive's identification, location, and findings. Photograph the comb. Notify the state apiary inspector promptly and request confirmation instructions, submitting a comb sample as directed – wrapped in paper, not plastic, in a cardboard box. If robbing seems likely, reduce or close the entrance. Await the inspector's instruction; destruction, treatment, and movement are governed by state law. What must not be done: transfer frames, bees, or equipment to any other colony; feed honey from this colony

to any other; extract or sell honey from it; move the equipment from the property; attempt to resolve the problem with antibiotics.

- The most defensible decision is to combine the two colonies over newspaper into one unit, removing one queen before combining. The essential condition is verified absence of disease and pest problems in both colonies – the scenario provides this, but in practice it must be confirmed, not assumed. Two four-frame colonies in early autumn in the southeastern US cannot reliably carry themselves through winter independently, cannot adequately defend against small hive beetle, and do not benefit from additional equipment. A single eight-frame unit has a real chance. The newspaper method prevents fighting by allowing two to three days for a combined pheromonal profile to develop before the colonies' workers make direct contact.

- A failing queen is present in the hive, lays eggs singly and centered at the base of cells, and shows normal egg-laying behavior; what distinguishes her is that an increasing proportion of her eggs are unfertilized, producing drone brood with domed cappings in worker-sized cells. The colony has not been queenless. Laying workers arise only after prolonged queenlessness – typically three or more weeks – and their eggs are scattered, multiple per cell, and placed on cell walls rather than the base center. No queen is present. The remedy for a failing queen is to locate and remove her and introduce a mated replacement; the workers accept a new queen normally. The laying-worker remedy is combination with a queenright colony rather than introduction, because the workers' quasi-queen pheromones interfere with normal queen acceptance and introduced queens are often killed. Attempting to introduce a queen into a laying-worker colony without the combined colony's support fails in the majority of cases.

- The two problems are a probable queen failure or loss, and probable underfeeding (a package with no laying queen also draws comb slowly) resulting in inadequate comb. The diagnostic step for the queen problem is inserting a test frame of eggs and young larvae from a healthy colony: if the workers start emergency cells on it within three to four days, the colony is queenless. If no cells appear, a queen may be present but failing. Both problems must be addressed simultaneously because a new queen, even if introduced successfully, has nowhere to lay without drawn comb, and comb cannot be drawn without adequate feeding. The queen problem addresses colony viability; the feeding problem provides the physical foundation for the colony to use a queen.

- The two most likely explanations for a less than 10 percent reduction in mite load are application error and resistance. Reinvasion does not explain it – an effective strip also kills immigrating mites over the application period, and the count was taken at strip removal. To distinguish the two explanations, review the application: dose for colony size, strip placement within the cluster zone, whether the strips were correctly installed and not displaced, product age and storage conditions. If application was sound, switch every colony above threshold to a product with a different mode of action now, without waiting – an extended-release oxalic acid strip is one option – and verify with a post-treatment count. To confirm resistance, run a field amitraz-resistance assay on mites from the failing colonies or ask the state apiarist or a university lab to test them. Do not leave infested colonies untreated as comparisons in late summer, while winter bees are being reared. If counts fall after the switch where the amitraz count did not, that points to resistance rather than application quality. The next step is to stop relying on amitraz as the primary tool in this operation until efficacy is reestablished or an alternative is selected.

- Before attributing the difference to any specific cause, verify it. Repeat the counts using consistent methodology, sampling nurse bees from brood frames in each colony on the same day. Check whether the three high-count colonies share a position in the apiary – colonies at row ends or nearest a neighboring apiary accumulate drifted bees and mites, and positional drift is a simple and common explanation. Review whether those three colonies share a queen source or queen age. If the difference persists after position and sampling are controlled for, treat those three immediately (they are at risk and are a reinvasion source for the yard) and then assess whether the pattern continues in subsequent seasons with new queens from a different source or with stock selected for documented resistance traits.

- Acknowledge the question as a good one that reflects a widely repeated belief, not a silly mistake. Explain the mechanism that makes the idea plausible: mites that fall through a screened board cannot climb back up. Then explain what the controlled trials actually found: that natural mite fall through a screened board does not reduce the population within the colony to a level that prevents damage, because the mites reproducing in capped brood far outnumber those falling off adult bees. Screened boards provide useful passive monitoring – a sticky board insert can give you a sense of relative mite activity – and some ventilation benefit. They do not replace treatment. Offer the references by name so the student can read the primary evidence themselves. The goal is to give the student the tools to evaluate claims rather than to substitute your authority for the prior authority they were following.

- Begin with your own data, documented rigorously: pre- and post-treatment counts from your own colonies showing that your treatments worked, followed by counts at intervals through autumn showing when mite levels began rising again and how fast. Compare counts across the apiary by position: if colonies nearest the neighbor's apiary show faster mite increases than colonies on the far side of your apiary, the gradient supports reinvasion as the explanation. Approach the neighbor directly, non-accusatorially, and share the data; offer to help with monitoring and explain the risk to their own colonies, since untreated colonies also eventually collapse from mite load. If the neighbor is willing to engage, help them set up a monitoring program and identify a treatment plan. If not, consider whether the local association, an Extension apiculturist, or the state apiary inspector has educational resources that might reach them. Adapt your own management: monitor more frequently, time treatments to catch the reinvasion before it compounds, and consider whether relocation is warranted if the situation continues without resolution.

- The plan works backward from the varietal bloom to the beginning of the season. Through early spring, build colonies to maximum strength and manage swarming aggressively – an artificial swarm, a Demaree, or preemptive splits – to keep the foraging force intact going into the sourwood bloom. Complete all mite monitoring and any needed treatment before supers go on, because many products require supers off. This is also when all previous honey is removed and extracted: the single most important step is clearing every super of honey from earlier flows before the target bloom begins, because anything remaining in the comb is extracted alongside the varietal and the single-source character is lost. Place clean, drawn supers at or just before the opening of the bloom. Remove them promptly when the bloom ends, before the bees add honey from subsequent forage. Keep that lot segregated through extraction, settling, storage, and bottling, handling gently to preserve color and aroma. Label accurately, citing the source only if you have information supporting that the named bloom was the primary source.

20.12 Further Reading

Delaplane, K.S. and Hood, W.M. “Economic threshold for Varroa jacobsoni Oud. in the southeastern USA.” *Apidologie* 30: 383-395, 1999. The foundational work establishing why thresholds are seasonal and regional; still the conceptual reference for the late-summer threshold.

Graham, J.M. (ed.). *The Hive and the Honey Bee.* Dadant and Sons, 2015 edition. The comprehensive American reference; the chapters on colony management, disease, and behavior underlie most of the scenario reasoning in this chapter.

Honey Bee Health Coalition. *Tools for Varroa Management.* 9th edition, 22 June 2026. The current standard reference for treatment options, thresholds, resistance, and monitoring methodology. Free download at honeybeehealthcoalition.org.

Lamas, Z.S., Rinkevich, F.D., Garavito, A., et al. “Viruses and vectors tied to honey bee colony losses.” *PLOS Pathogens* 22(2): e1013939, February 2026. The study documenting 100 percent amitraz resistance in screened mites and elevated ABPV and DWV-B prevalence; essential reading for understanding the current management landscape.

Sammataro, D. and Avitabile, A. *The Beekeeper’s Handbook.* 5th edition, Cornell University Press, 2021. Accessible reference covering management, disease, and queen biology with practical orientation.

Shimanuki, H. and Knox, D.A. *Diagnosis of Honey Bee Diseases.* USDA Agriculture Handbook 690, 2000. The standard field guide for disease identification; the AFB diagnostic criteria and the foulbrood containment protocol originate here.

Laidlaw, H.H. and Page, R.E. *Queen Rearing and Bee Breeding.* Wicwas Press, 1997. The authoritative reference on queen introduction biology, including why unverified queenlessness produces introduction failures.

Delaplane, K.S. and Mayer, D.F. *Crop Pollination by Bees.* CABI, 2000. The basis for understanding colony strength as the measure of pollination value; why frames of bees is the right unit.

Ellis, J.D., Delaplane, K.S., and Hood, W.M. “Efficacy of a bottom screen device, Apistan, and Apilife VAR in controlling Varroa destructor.” *American Bee Journal* 141: 813-816, 2001. The controlled-trial evidence on screened bottom boards and Varroa control; the reference to offer when teaching the screened-board misconception.

Frey, E. and Rosenkranz, P. “Autumn invasion rates of Varroa destructor into honey bee colonies and the resulting increase in mite populations.” *Journal of Economic Entomology* 107: 508-515, 2014. The quantitative data on mite reinvasion in autumn; essential for understanding why post-treatment counts rise again and how to interpret the pattern.

Neumann, P. and Elzen, P.J. “The biology of the small hive beetle (*Aethina tumida*, Murray, Coleoptera: Nitidulidae): gaps in our knowledge of an invasive species.” *Apidologie* 35: 229-247, 2004. Foundational review of beetle biology, including the conditions that favor slime-out.

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University of Georgia Cooperative Extension. Bulletin 1045, *Honey Bees and Beekeeping*. The most directly applicable regional management guidance for the southeastern US; available through UGA Extension.

University of Florida IFAS Extension, Honey Bee Research and Extension Laboratory. Publications on small hive beetle biology and management, Varroa monitoring, and Florida-region apiculture. Available at entnemdept.ufl.edu/honeybee.

US Food and Drug Administration. “Proper Labeling of Honey and Honey Products.” Guidance for Industry, February 2018. FDA’s non-binding recommendations on identifying honey, declaring added sweeteners, and naming a floral source; the enforceable requirement is the FD&C Act’s prohibition on misbranding.