Georgia Master Beekeeper Lecture Series
LECTURE 1—WHAT ARE BEES?

I. Bees are Insects

A. Interesting facts

- There's 3 times more insects than any other form of terrestrial life.
- ~1000 species in a normal backyard
- ~1,000,000 insects per acre
- wt. ants > wt. of all other land animals
- benefits: pollination, predators, recycle nutrients, turn soil, recycle wastes, dead carcasses, dead wood, turn soil, shape ecologies (ie. fire ant in southeast: in LA has eliminated ticks, in GA has eliminated other ant species.)
- pests: $750,000,000 in GA, herbivory, livestock parasites and pests, fire ants, urban tramp species (*C. formosanus*, *Monomorium*; at Harvard Univ., a colony of *Monomorium* tracked radioactive materials from lab dishes to walls), human parasites and illnesses, disrupt ecologies, venomous insects

B. What are insects?

- Animal Kingdom
- Some major phyla: Protozoa (single-celled), Coelenterata (jellyfish, corals, sea anemones), Mollusca (clams, snails, octopi), Annelida (earthworms, leeches), Chordata (fish, amphibians, reptiles, birds, mammals)
- subphylum Crustacea
- phylum Arthropoda—segmented body "jointed foot"
- Some of the classes: Merostomata (horseshoe crabs), Arachnida (spiders), Diplopoda (millipedes), Chilopoda (centipedes)
- class Hexapoda—6-legged
- Three body regions or tagmata: head, thorax, abdomen and functions
- 1 pr. Antennae, 2 pr. Wings, 3 pr. Legs
- incomplete vs. complete metamorphosis

C. Order Hymenoptera

- "membranous wings" or Greek for "marriage" (of wings to hamuli)
- humanly-speaking probably most beneficial order. Good predators and parasites and pollinators
- complete metamorphosis
- sex is determined (for practical purposes) by gene dose: haploid (non-fertilized) eggs become male, diploid (fertilized) eggs are female
- 4 wings, hind smaller with hamuli, stinging ovipositor
- suborder Symphyta is the "broad-wasted" Hymenopterans, including sawflies. Nearly all are phytophagous.
- suborder Apocrita includes "slender-wasted" Hymenopterans, including parasitic wasps. Waist provides flexibility.
- subgroup Parasitica or "nonstinging"
- subgroup Aculeata or "stinging" includes ants, bees, and hunting wasps
- Wasps sting prey and larvae are carnivores; bees sting for defense and larvae vegetarians

D. Bees

- Belong to superfamily Apoidea, which includes sphecoid wasps and bees.
- pronotal lobe is small and does not connect to the tegulum

- pronotal processes meet ventrally
- Sphecoids and bees also share in common the habit of cleaning the thoracic dorsum by forward scraping motions of the middle tarsi; other hymenopterans use front tarsi.
- But now we separate the true bees (Apiformes) from the Spheciformes:
- Bees have specializations for vegetarian diet: broadened hind basitarsi (this can id a cleptoparasitic species that otherwise is hairless and looks like a wasp), branched hairs (wasps' are single), stomach filter, mouthparts that fold into a long nectar-sucking tube
- 25,000 species of bees, compared to 5,500 reptiles+amphibians, 8,600 birds, 3,500 mammals
- 4,000 bee species in North America; 5 families in eastern U.S: Colletidae, Andrenidae, Halictidae, Megachilidae, Apidae
- Most species diversity is found in dry xeric habitats of the world: California, Israel, Mediterranean.

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LECTURE 2—MORPHOLOGY, CLASSIFICATION, IMMATURE DEVELOPMENT

I. Morphology

A. Major body regions

- head, vision, brain, antennae, mouth, esophagus, glands
- thorax, muscle for heat-generation and locomotion
- petiole is constriction between thorax and abdomen
- abdomen, digestion and reproduction

B. The head

- 2 compound eyes, three auxiliary eyes called ocelli which cannot focus and form images are used solely for determining light intensity or to regulate diurnal activities and orientation
- one pair antennae, smell (olfactory acuity of bees is about same to man, but bees are 10-100X more sensitive to odors of wax and flowers). Antennae also can determine direction of smell. There may be sensors for carbon dioxide, taste, humidity, and possibly temperature. The Johnston's organs, inside antennae, are sensitive to minute changes in antennal bending which measures flight speed.
- genae, region between mandibles and bottom of eye, useful in diagnosing families.
- mandibles + internal mandibular glands—brood food gland for workers, mandibular gland for queen, mandibles used for biting, carrying, chewing, and molding wax
- tongue or proboscis, used to suck up fluids, feed each other (trophallaxis), and receive pheromones. Tongue length often dictates what types of flowers bee can visit.

C. The thorax

- Notum is dorsal plate for thorax
- Sternum is ventral plate for thorax
- prothorax ~ pronotum (Snodgrass handout: N1, L1, spl = pronotal lobe of lecture 1) Note that there's no S1; this is one of the defining characters of a bee as in lecture 1. It is the pronotum that wraps around and joins on the venter without a distinct ventral sclerite.
- mesothorax (N2, S2, L2, Tg)
- metathorax (N3, S3, L3)
- the propodeum (IT) is actually the anterior-most abdominal segment. During pupation it crowds against the thorax and becomes superficially a part of it. Note the abdominal spiracle on the "thorax."
- 3 pair legs, one on each section of thorax
- 2 pair wings
- heavily tracheated
- thoracic muscles are also involved in heat production

D. The legs

- coxa
- trochanter(s)
- femur
- tibia (broadened on hind legs to constitute the corbiculum)
- tarsus, 5 segments first of which is basitarsus
- basitarsus (is broadened on hind leg to form pollen brushes)

  See Snodgrass pp. 109-110. Pollen is raked off front of body by front legs, passed to mid legs, and mid legs are raked between the combs on inner side of rear basitarsi. Opposing basitarsi rub against each other and the rakes (*ras*) on the distal end of pollen scrape pollen onto the pollen press; the bee then flexes the pollen press and it pushes the pollen load up into the corbiculum on the broadened outer side of the tibium.

- antenna cleaner (on basitarsus of foreleg)

E. The wings

- forewing
- hindwing
- hamuli
- submarginal cells
- basal vein
- first and second recurrent veins
- indirect flight—longitudinal and dorso-ventral muscles cause thorax to flex. Wing base pivots on a fulcrum. Secondary muscles pivot wing to allow side-ways flight. Indirect musculature is much more efficient than direct musculature. The hindwings have muscles to raise them, but are pulled down only by their attachment to the forewings via the hamuli. Other muscles allow wings to fold back. Wings can be "unhooked" to allow shivering.

F. The abdomen

- reproductive system, emphasize female system. Ovaries are poorly developed in workers, well developed in queens. Ovaries joined by lateral oviducts to a common middle oviduct where there is a spermatheca. Workers and queens both have spermathecae, but workers' are poorly developed. Queen has muscular control of releasing sperm.
- gut—esophagus, crop (muscular for nectar transport), proventriculus (contains "teeth" [proventricular valve] for straining out pollen from crop contents), midgut (absorption), kidneys (excretory or malpighian tubules) permeate throughout abdominal tissues, rectal pads (H_2O reclamation?), and rectum (reservoir)

G. Other systems

- dorsal blood vessel, an open system in which blood flows freely in body cavity. Blood enters heart in one-way valves called ostia and muscle contractions push it forward down the aorta and dumps it on brain. The loops at the petiole in bumble bees serve to heat the abdomen for incubating brood clump
- ventral nerve cord, a brain (cerebrum), concentrated around compound eyes with seven ganglia down a ventral nerve cord
- respiratory system, invaginations of cuticle at outer openings called spiracles that make tubules or sacs. Inactive gas exchange until bee gets active, then it actively pumps its abdomen to increase air exchange.

II. Classification

A. Higher taxa

- Phylum Arthropoda—"jointed foot", segmented body.
- Class Hexapoda (or Insecta)—"six-legged"
- Order Hymenoptera—"membranous wings" of "marriage" of hind and fore wing. Includes ants, wasps, and bees.
- Suborder Apocrita—slender wasted
- Subgroup Aculeata—"stinging" Hymenopterans
- Superfamily Apoidea—bees and sphecoid wasps

B. Families of bees. There are 7-11. The latest authority, Michener (2000) says 7. We will mention only six.

- Colletidae—digger bees, polyester bees, includes common Georgia species *Colletes thoracicus*, short tongued and bilobed, second recurrent vein sigmoid
- Andrenidae—digger bees, short tongued, second recurrent vein straight
- Halictidae—sweat bees, basal vein strongly arched
- Megachilidae—leafcutting bees, mason bees, orchard bees, long tongued, 2 submarginal cells

- Anthophoridae—some are digger bees, includes carpenter bees; a 1993 paper lumped anthoporids into Apidae, long tongued, 3 submarginal cells, narrow genae
- Apidae—includes bumble bees (*Bombus*) and honey bees (*Apis mellifera*), long tongued, 3 submarginal cells, genae broad
- Mimicry—"bees" that aren't bees

III. Immature development

- egg hatches after a few days (3 in *Apis*), shell disintegrates
- Larvae are eating machines, no eyes, antennae, legs. Fed pollen+nectar or glandular secretions. Molts 4-5 times; each stage called an instar. Midgut is not connected to hindgut during feeding phase. Defecation and molt to prepupa. Fecal pellets may be incorporated into cocoon. In Apis the cocoon is greatly minimized.
- prepupa—an elongated larva; very common overwintering stage in solitary bees. Last larval skin then sheds to reveal the pupa.
- Pupa—reorganization of internal tissues. Wing buds are apparent. Colorless pupal skin is shed when the adult cuticle has hardened to reveal complete wings. Wings are expanded by pumping blood into their veins; the cuticle hardens and the bee emerges.
- development time is highly variable depending largely on the life history of the species. In solitary species in which there is no temperature regulation the development of each stage can speed up or slow down according to ambient conditions. In well-developed societies, however, temperature is closely controlled and development time is very programmed, rigid, and predictable.
- 2 divergent pathways: (1) fertilized or not and (2) (in social bees) well-fed or not.

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LECTURE 3—BASIC LIFE HISTORY OF BEES, SOLITARY VS. SOCIAL BEES

I. Basic Life History of Bees

A. Vegetarian diet

- pollen for protein (although some S. American social bees eat carrion)
- nectar for energy (although some are opportunists and go for sugar in any form)
- in some social species, larvae are fed "bee milk", "royal jelly", or "worker jelly." These are metabolically derived from pollen and nectar.
- nectar is added to pollen, eaten as-is, or dehydrated into honey
- mass-provisioning
- progressive provisioning—more variable results, depending on seasonal richness. Also in social colonies this permits control on an individual's development.
- larvae live in food and must postpone defecation. Hindgut is separate from midgut until just before elongating to a prepupa.

B. Nesting Habit

- universal in bees except for cuckoo species and many males
- this requires ability to identify landmarks, forage randomly in habitat, and find nest again.
- most nests are simple burrows in wood, soil, or plant stems, or pre-existing tunnels. More complex species construct nests of natural materials or synthesized materials (beeswax).

C. Sex determination

- Females mate and store sperm for life.
- Females have muscular control over fertilizing eggs. Fertilized=female; non-fertilized=male. This is important in perennial colonies which must time production of males. In solitaries important too to make sure males are at front of nest.

II. Grades of sociality

- solitary
- cooperative care of brood
- reproductive division of labor so that more-or-less sterile individuals working on behalf of fertile individuals.
- overlap of at least two generations so that offspring help their mother produce more siblings.
- possessing all three is *eusocial*; all grades between mating behavior and eusociality is called *presocial*.

III. Solitary bees

- of the 4,000 bees in N. America, vast majority are solitary.
- usually only 1-2 generations per year
- immatures overwinter, males emerge first, then females, mate, females provision cells, put male cells to the front.
- highly seasonal, very specialized on plants blooming during nesting season. Specialized flower behaviors: buzzing, fast speed.
- solitary bees are flower specialists; long-lived social colonies are flower generalists.
- miner or digger bees: nest architecture, cell linings; Colletidae, Anthophoridae, Anthophoridae
- masons and leafcutters nest in existing cavities, partitions of mud or leaf; Megachilidae
- carpenters; nest in successive years
- nest aggregations

IV. Communal bees

- share common nest entrance, but each provisions her own cells

- same generation, sometimes siblings, all females mated
- examples exist in Andrenidae, Megachilidae, and some halictids

V. Quasisocial
- share common nest entrance
- same generation, sometimes siblings, all females mated
- cooperate in building cells
- few real examples; mostly when no. cells is < no. bees which suggests that some are co-laboring on common cells

VI. Semisocial
- share common nest entrance
- same generation, sometimes siblings, sometimes <u>not</u> all females mated (beginnings of division of labor)
- cooperate in building cells
- a few halictids fit this category

VII. Subsocial
- Female plus her immature offspring (maternal care)
- progressive provisioning is the norm, and the mother usually dies when offspring mature
- progressive feeding

VIII. Primitively eusocial
- mother goes through solitary phase
- offspring emerge and help mother (=overlapping generations = eusociality)
- *Bombus*

IX. Eusocial bees
- cooperative brood care
- reproductive division of labor
- overlapping generations
- makes possible a perennial colony

X. Social parasites (cuckoos)
- common in *Bombus*
- no castes, just females and males
- female invades nest, takes it over, and dupes workers (via chemical mimicry) into producing her offspring
- inquilines are more-or-less harmless nest dwellers. Also use chemical mimicry.

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LECTURE 4—THE GENUS *APIS*, *APIS* BIOGEOGRAPHY, SEXES AND CASTES

I. The genus *Apis*—the honey bees

A. Generalizations

- originally exclusively Old World
- most species in India and southeast Asia, all species are there except *A. mellifera*
- four species
- all are perennially eusocial
- two groups: (1) single comb in the open (*A. florea and A. dorsata*), (2) several combs in cavities (*A. cerana, A. mellifera*)

B. *Apis florea*

- dwarf honey bee
- one, small comb, surrounded by dense vegetation; rings of resin at attachment of comb to protect against ants
- comb is extended at top as a dancing platform; bees point straight at sun
- migratory up and down elevations in response to temperature or nectar
- honey hunters

C. *Apis dorsata*

- giant honey bee
- single large comb
- high in trees, cliff faces
- migratory up and down elevations for nectar
- vertical comb dances
- honey hunters

D. *Apis cerana*

- eastern honey bee
- cavity dweller
- it fans with abdomen <u>toward</u> entrance
- very large range, Afghanistan to Japan
- managed for honey production, but imported *A. mellifera* usually more productive
- side-by-side, *A. mellifera* and *A. cerana* rob each other. In Japan, imported *A. mellifera* has excluded native *A. cerana*.
- matings cause lethal offspring
- *Varroa*

E. *Apis mellifera*

- western honey bee
- cavity dweller
- southern Africa to Scandinavia
- 24 subspecies
- 3 biogeographic regions: African, Near-East, European

II. *Apis mellifera* biogeography and races

A. *capensis*

- cape bee
- workers have well-developed ovaries and spermathecae, but spermathecae do not have sperm
- parthenogenesis

B. *scutellata*

- east African honey bee

- imported into Brazil in 1957
- in Brazil it freely hybridizes and excludes other *Apis*

C. *monticola*

- coexists with *scutellata*
- gentle

D. *adonsonii*

- west African honey bee
- originally all honey bees south of Sahara and north of cape

E. *carnica*

- Carniolan
- southern Austrian alps
- gentle
- dark
- overwinter well
- build up quickly
- swarms readily

F. *caucasica*

- Caucasian
- gentle
- build up slowly
- poor overwintering due to Nosema
- propolis

G. *mellifera*

- German black bee
- northern Europe
- dark, mean
- winter well
- slow spring buildup
- afb
- in Virginia by 1622

H. *iberica*

- Iberian peninsula
- dark, defensive
- nervous on comb
- lots of propolis
- swarm a lot

I. *ligustica*

- Italians
- yellow bands
- docile
- quick buildup
- overwinter well but eat a lot of food
- build comb fast

III. *Apis* Biogeography in North America

- two periods of colonization—1622 onwards from European settlers, primarily with *A. mellifera mellifera* and *A. mellifera iberica,* then again 1859-1922 when queen breeders actively imported a variety of European and African stock. This was made possible by the advent of regular steamship service.

- By 1800 *A. m. mellifera* were common along East coast, “white man’s fly.” They were introduced to California in 1853. *A. m. mellifera* and *A. m. iberica* were the only Apis in North America for 200 years.
- *A. m. ligustica* was introduced to New York in 1859 and disseminated by breeders in Pennsylvania and New York
- *A. m. carnica* was introduced in 1877
- Today North American *Apis* exists largely in commercial and hobby apiaries. The presence of exotic parasites has seriously damaged sustainable feral populations. However, there remains some evidence of persistent geographical variation in the range of these imported subspecies.
- Mitochondrial DNA is inherited only maternally and varies much less over time as does nuclear DNA. Thus, it is a good tool for examining biological history.
- Nationally, 62% of <u>feral</u> honey bees exhibit *ligustica/carnica* mtDNA; 37% exhibit *mellifera/iberica* mtDNA. In Georgia it’s 73% *ligustica/carnica* and 23% *mellifera/iberica*, but in Arizona it’s 30% *ligustica/carnica* and 68% *mellifera/iberica*

IV. Sexes and Castes

- *caste*—a different form, morphologically or reproductively, <u>within the same sex</u> of a species

A. Males or drones

- haploid, one set of chromosomes; but there is an exception to this that can be experimentally manipulated to produce 2X drones.
- 24 days to develop
- colony has 0-500 drones in spring and summer
- largest eyes

B. Workers

- fertilized egg, two sets of chromosomes
- 21 days, although 19 in Louisiana
- 3000-60,000 workers in a colony
- most complex behaviors and morphology of any individual bee
- a predictable sequence of tasks:
  cap brood
  clean cells
  feed brood
  receive nectar
  clean hive
  orient to hive
  guard duty
  forage
- reversion possible
- morphology specializations: corbiculum, antenna cleaner on front leg, brood glands, barbed stinger
- “winter bees” six months
- “summer bees” three weeks
- if queenless, ovaries can develop

C. Queens

- fertilized egg, identical to worker
- 16 days
- less complex morphology and behavior
- fed and cared for by workers
- but complete ovaries and spermatheca. Spermatheca nourishes sperm.

- up to 2,000 eggs per day
- mandibular gland produces “queen substance” (9-ODA)—pheromone that regulates behavior of workers and other bees. Helps swarms orient.

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LECTURE 5—NEST ARCHITECTURE

I. Cavity characteristics and locations

- when swarm issues, it must quickly find new nest site before workers' crop contents used up; it must also be a site where the colony can live for years.
- swarm scouts may begin looking for site 3 days before swarming; return to nest and do recruitment dance
- swarm must also move far enough away that they don't compete energetically with parent colony, but not so far away that they burn up all their crop contents; 500-600 meters seems to be the optimal distance they can move away.
- swarms in temperate climates must avoid cavities that are too small, but can't be so big that temperature maintenance and defense are problems. Cavity volumes range from 20-100 L, and 40L is average (Langstroth hive body is 42 L)
- tropical races prefer smaller cavities; South American AHBs occupy cavities occupy 22 L and as small as 7 L. Some tropical *Apis* avoid cavities. Small cavities are the norm in tropics because they need less space for food storage and intense predation pressures make a smaller nest easier to defend.
- need insulated material. 3/4-inch wood is marginal; wood good material for absorbing metabolic water. Also upper entrances or a big cavity to simply displace water vapor
- In New England, most feral nest entrances are >3 m above ground
- partial wind and sun protection
- South-facing entrances are norm. Entrances usually in knotholes, tree cracks. Single entrances are the norm. Again a compromise—heat retention in winter, and defense and heat dissipation in summer. Entrances are usually below the area where bees build their comb.
- absence of gaps or cracks, but bees can partially seal them off with *propolis*—tree resins which are also partly antimicrobial
- There is no consistent preference for cavity shape.
- Swarms accept cavities with wet floors and drafts. Workers can seal off much of a wet area with propolis.

II. Comb architecture

- swarm bees often already have wax flakes coming out of their glands. Rapid comb construction is paramount. Nothing can happen without it. Over 90% of a feral colony's comb construction is finished within 45 days.
- hexagons most efficient and strong
- typical nest has 100,000 cells in a total comb surface area of 2.5 m^2; takes 1,200 grams of wax to build a colony's combs and colony consumes 7.5 kg wax to metabolically produce this.
- honey bees build their cells horizontally rather than vertically, and inclined slightly (13°) upward from the midrib.
- cell size varies by bee race and colony age. Tropical races tend to be smaller. Also, new colonies' cells tend to be extremely uniform in diameter (5.2-5.4 mm in *ligustica*) whereas older colonies may vary due to sagging from heavy loads of honey. Precision of construction is extreme; cell wall thickness is 0.073 ± 0.002 mm and the angle between walls is exactly 120°.
- bee space 3/8-inch
- two sizes of hexagonal cells: worker and drone; drones usually grouped at comb edges because they are expendable if it gets cold.
- queen cups, queen cell foundations ready-to-go. They may be a behavioral deterrent to queen cell construction, yet at loss of queen they can be immediately put to use.

- queen cells, about 10-20 at a time, and torn down after emergence. Occur at bottom and sides of combs.
- Secreting workers “festoon” and cluster to raise temperature to 35°C, the best temp for secretion and wax manipulation. Wax flakes are removed from ventral glands by hind leg and passed forward to front legs and mandibles where they it is mixed with saliva and kneaded to proper plasticity. Each scale takes 4 minutes, or 66,000 bee hours to produce the 77,000 cells possible from 1 kg of wax. This same 1 kg of comb can hold 22 kg of honey, over 20 times its own weight.
- construction seems to be random, with several cells under construction simultaneously. Work begins on the roof or side of the cavity, with 2-3 construction sites per comb (in managed colonies with foundation they start in the middle). Thick wads of wax are placed at the midrib and these are drawn out into cells by elongating and thinning the wax into the cell walls.
- Workers use hair plates at the base of the neck as a plumb bob. Shifting pressure on the plates tells the bee which direction is up. They use tips of antennae to determine thickness of cell walls.
- brood in middle, pollen, pollen+honey, then honey; honey is at the points of attachment for strength
- empty cells in middle during winter
- honey bees do not recycle wax as much as do other bees. Combs tend to be permanent.
- cells tend to get smaller in time due to accumulated debris
- combs darken and get smaller in time; is this a problem for managed hives? Wax moths destroy old combs in nature.

III. Comb as affecting sociobiology

- comb is substrate for dance.
- the degree of comb occupancy is a feedback loop to foragers to forage more or less for a substance.
- comb is substrate for pheromonal cues for cell capping, cell repairs, and queen cell construction, nectar storage, and colony odor signature.
- combs transmit vibrations in waggle dances
- Jennifer’s research: Colonies on new comb had higher area of brood and heavier emerging bees. However, brood survivorship was higher in old comb. Explanation? Apparently, the queen prefers to lay eggs in new comb, but once an egg is deposited its chances of survival are best in old comb perhaps due to sequestered brood pheromones that help nurse bees orient to larvae. Nevertheless, the benefits of enhanced queen egg-laying rate were higher than the benefits of enhanced brood survival.

Georgia Master Beekeeper Lecture Series
LECTURE 6—HONEY BEE SEASONAL LIFE HISTORY

I. Review, the two generalities

- perennially social honey bees must survive a long period of cold and food dearth
- must reproduce early enough to let offspring colony build up a food reserve

II. Terms

- there's two levels of honey bee reproduction: the individual, and the colony
- "swarm" is a potential colony in transit to a permanent home site

II. Pre-swarm preparations

- distal cues for swarming: time of year, daylength, nectar availability, warm weather
- queen cups are year-round foundations for queen cells
- in healthy colony, by mid-spring, queen lays eggs in 20 or more queen cups; number of newly-made queen cups increases in weeks before swarming.
- queen rearing begins when worker production is at its peak and there are few empty cells.
- workers feed them royal jelly, cells are elongated downward. Many cells are destroyed by workers or the queen during this period. Colonies seal an average of 15-25 cells before swarming. This helps ensure parent colony gets requeened.
- cells are often destroyed duing periods of bad weather. Swarming must coincide with good nectar flow conditions, and cell destruction will delay swarming if necessary.
- proximal cues that initiate swarm cell production: Brood nest congestion, population, worker age distribution (lots of young bees), and reduced distribution of 9ODA; each worker needs to receive ~ 0.1µg 9ODA per day to be inhibited from producing queen cells.
- during spring queen is fed more and more, until the week before swarming when workers begin feeding her less and her egg production drops
- shake queen with head or forelegs (4-5 bursts); from 40-80 bouts per hour; keeps queen walking around nest and loses 25% body weight. During this time she may examine and destroy queen cells.
- scout bees may go looking for new nest sites. Workers become quiescent immediately before swarming.

III. The Swarm

- Workers engorge with honey for about 10 days prior to swarming, due to unpredictability. There's an average 36 mg honey in crops instead of the usual 10 mg in non-swarming colonies.
- proximal cues that initiate issuing of swarm: first queen cell capped, nectar flow, warm and sunny afternoon.
- On day of swarm workers begin running in waves across combs, exciting each other. Queen is chased and bitten. Suddenly a wave rushes out the entrance, taking the queen with them. A "false swarm" may issue and return if the queen is not with them.
- Queen flies off with up to 60% of workers (10-15,000 workers)—*prime swarm*
- they cluster, and QMP helps orient workers to the site. Scouts look for permanent site (recall earlier lecture on nest sites), and swarm relocates. Scouts recruit the cluster with waggle dances; there may be competing dances going on simultaneously. Scouts "steer" the airborne swarm by performing "streaking" flights through swarm in direction of new nest.
- Younger workers are more prone to go with a swarm. Up to 70% of workers < 10 days old will join the swarm. This is important for the swarm to have a supply of long-lived bees until the first brood emerges 21 days later.

- Also, workers tend to proportionately go with queens with whom they are full, instead of half, sisters. But, there are conflicting data for this.
- for a few days the colony is queenless, but workers emerge so populations rebounds a bit by the time first daughter emerges
- Back at parent colony depending on population size, workers either let new daughter kill her rivals in their cells, or guard them (workers imprison new queens in their cells and don't let them emerge). Queens exchange audible signals called "piping" or "quacking." Not sure of the function of these signals.
- brood mortality is high during this phase.
- if a secondary swarm (or *afterswarm*), workers shake new daughter queen to keep her agitated, then she flies off with the swarm
- process repeated until colony is too weak to be split any more
- workers let last daughter kill rivals
- colonies spend rest of season rebuilding strength and storing food for winter

IV. Supersedure

- Queen replacement, can happen any time of year that resources permit production of queens.
- Usually happens when queen is failing, whether from reduced egg production or reduced 9ODA.
- Cells tend to be more centrally located on comb instead of periphery like swarm cells.
- Supersedure queens tend to be inferior, partly because workers may choose larvae past the optimum 12 hour age window. It is possible to experimentally manipulate time of royal jelly feeding to create intercastes.

V. Role of the Drones

- Workers begin producing drone cells before queen cells. The cells (one of the "horizontal" types of cells are larger and the queen detects them with her forelegs and deposits non-fertilized eggs.
- Drones emerge during the swarming season. When 4 days old they begin leaving on mating flights, traveling short distances to special "drone congregation areas" where they meet with drones from other colonies in the area. They hover here in sustained flight and await virgin queens. These DCAs orient toward visible landmarks and tend to be consistent year after year (always with different individuals).
- A virgin queen is urged out of the nest by mildly aggressive behavior of the workers and she takes wing. As she approaches a DCA she emits 9ODA from mandibular glands and as it disperses downwind it attracts males from a distance of 10 meters or more. Mating is in the air and lethal to the male who is instantly paralyzed and drops to the ground. The queen makes up to three flights per day, up to 12, and mates with 7-17 drones. She stores their sperm in her spermatheca and this one period of mating is sufficient for a lifetime supply.
- The newly-mated queen either participates in an afterswarm or else destroys her rivals and takes over the nest.

VI. Energetics of Reproduction

- typical colony uses 33-66 lb pollen and 130-175 lb honey per year (remember in GA we need about 30-50 lb honey just for winter)
- a typical nectar or pollen load weighs 10-40 mg, so it takes 1 million bee trips per year to collect enough pollen, and 4 million trips to collect nectar
- Most of the year is a dearth. In Connecticut, 86% of a colony's weight gain occurred between April 16-June 30; just 75 days
- new swarms must not only collect enough food, they must also make a nest which is energetically costly. One reason swarms often cued with nectar flows.

- In NY, only 24% new swarms survived first season, but 1-yr. old colonies survival was 78%; these one-year survivors lived an average of 6 years.

VII. Thermoregulation in Hot Weather

- bees collect water and place it around hive surfaces
- then fan air in a circular fashion to cool nest by evaporation
- individuals cool themselves in flight by regurgitating water droplet on tongue and extending it in front of them like a radiator.

Georgia Master Beekeeper Lecture Series
LECTURE 7—HONEY BEE COMMUNICATION, FORAGING BIOLOGY, AND DEFENSE BEHAVIOR

I. Review of enormity of annual foraging requirements

- combined pollen and nectar needs sum up to 5 million bee trips per year
- this is from widely-scattered resources, so bees must forage efficiently

II. Why recruit? and early proof

- Honey bees recruit; bumble bees, with an annual life history, do not recruit
- Maeterlinck (1910) let a worker find syrup dish, return to colony, caught when she left for another trip, but other workers nevertheless showed up at the dish

III. Round dance is simplest dance

- Does not communicate precise distance or direction. It simply informs workers that there is a resource close the nest (15-25 m).
- Run in circle and pass along nectar. Recruits fly in large orbits around nest until they locate resource (probably by odor and previous experience).
- More concentrated the food, the more vigorous the vibrations, but this is seasonal. When in dearth, lower sugar concentration threshold triggers very vigorous dancing. Good for nectar and pollen (how do they communicate pollen quality?)

IV. Waggle dance

- communicates information about distance, direction, and quality. Good for distances 100m. Figure eight.
- Spectators may release begging signal (squeak), and dancer stops and shares food. Recruits "encourage" dancer by their eager acceptance of her crop contents. Good for nectar and pollen. As in round dance, in dearth times response threshold of recruits is lower.
- Direction communicated via angle of resource to sun (=angle of straight run to top of comb).
- Distance communicated via: length of straight run (in comb cell diameters), duration of wagging and buzzing during straight run, no. circuits per unit time, and distance of dance from entrance. Slower tempo = more distance; longer straight run = more distance. Bees communicate not absolute distance, but energy to get there. If experimenter adds weights to bees, or if they must fly into the wind, the straight run is longer. As distance communicated increases, recruits take more honey for the trip.
- Many bees watch 6-7 dances and average the information. When they get close enough to resource, odor and visual cues kick in.
- There is 9-12° error rate in direction, and 2-10% error rate in distance by recruits. On average, less than half of recruits find resource at first try; most need 2-5 flights before they succeed. Reasons for inacuracy in waggle dance: dance tempo decreases in older bees so that they communicate greater distances than when they were younger, younger bees are less experienced at reading dances.
- Similar distance and direction dances are used to collect water, propolis, pollen, and by swarms to recruit to new nest sites.

V. Transition dance

- for distances between 25-100 m
- numerous dialects between races for this dance

(Showed ~5 minutes of Guelph video, *Dance Language of the Honey Bee*)

VI. The vibration dance

- worker grabs another bee and vibrates its body up and down
- vibrated workers move into areas of the nest where there are waggle dances. The vibrators are often pollen foragers.
- also used on queen before swarming. It inhibits her activity, possibly prevents her from destroying developing queen cells, slows egg production, and exercises queen.

VII. Foraging

- honey bees are extremely efficient at harvesting a habitat's available energy and protein resources.
- productivity of a region can vary due to drought and successional stage of plants. A fire, for example, can result in very rich early-succession plants in the first or second seasons.
- some of the best world-wide plants that can make >500 kg honey per hectare include: common maple, milkweed, phacelia, sage, thyme, acacia, and figwort. In Georgia the best are maple, gallberry, clover, tulip poplar, sourwood, and blackberry.
- In agricultural areas bees usually forage within a few hundred meters of the colony; in forested areas it's larger, about 1.7 km.
- Significant foraging has been found at 3700 meters, and recruitment to 10,000 m has been done if no other food is available.
- Bees see UV light. Thus, the sun is a navigating tool. Also, many flowers floresce at UV and thus are targets to aim bees at nectaries.
- bees see white, black, yellow, blue-green, blue, and UV; do not consistently see red. Thus, red flowers are more specialized for birds, not bees.
- bees recognize landmarks
- most prefer nectar collecting: 58% are nectar collectors, 25% collect pollen, and 17% both nectar and pollen; most bees visit one species of flower per trip
- both nectar and pollen collectors need 1-500 flowers to collect a load, depending on the productivity of individual flowers.
- Both nectar and pollen foragers make 10-15 trips per day. Nectar foragers may do up to 150 trips. Time per trip is ~10 minutes for pollen collectors and 30-80 minutes for a nectar trip. Nectar tends to be more dense than pollen, so it takes more energy for bees to collect nectar; nevertheless, nectar foraging tends to be energetically more profitable.
- Must figure in cost of energy expended for the trip. Usually, income ratio is 8:1 (calories gained : consumed) for pollen collection, and 10:1 for nectar
- Nevertheless, workers will fly further to collect pollen, probably because it is lighter and colonies do not store large quantities of pollen which may necessitate them to fly further to keep fresh supplies.
- if rewards are high, a bee may visit the same flower patch her entire life
- Ways to visit a flower: <u>open flowers</u>, "scrabbling"–bee bites anthers and pulls anthers toward her body. <u>Tubular flowers</u>, bee inserts mouthparts and pollen is collected inadvertently. <u>Closed flowers</u>, bee forces petals apart with forelegs and gathers pollen on mouthparts and forelegs. <u>Spike flowers</u>, bee runs along spikes and shakes pollen onto her body hairs. <u>Presentation flowers</u>, bee presses abdomen against inflorescence, causing pollen mass to come out and adhere to body. These pollen packets are called 'pollinia.'
- winter flight possible at 32 degrees, but serious foraging not until 54-57
- a "feedback loop" regulates foraging. House bees encourage nectar foragers by eagerly taking their loads from them.
- The proportion of pollen foragers increases in presence of eggs and brood. Also, the queen's pheromones stimulate foraging.

- Nectar foraging is stimulated by presence of queen, presence of worker larvae, and empty comb.
- From 5-35% of a colony's foragers can be serving as scouts (workers that return with a load without having watched a dance). Proportion goes up in dearth, thus increasing chance of finding something.
- Thus, the hive is an "information center" where scouts communicate new resources and recruits appraise the dance based on its quality. Returning foragers are either encouraged or discouraged to continue on the same resource based on the eagerness with which they are relieved of their loads.

VIII. Defense Behavior

- It is not "aggression," but "defense."
- necessary because nest is a bonanza of energy for a predator
- especially effective against large predators, including humans
- in sequence: guard bees note threat at entrance and alert nestmates by posture and release of alarm pheromone from the sting and mandibular glands.
- Alerted nestmates leave nest and search for attacker, orienting to such stimuli as: motion, color contrasts, vibration, and scent. Dark colors, rough textures, animal scents (CO_2) all aggravate the bees.
- Once attacker found, bee performs threat behaviors prior to stinging: threat posture (raising sting), buzzing, burrowing into hair, biting, pulling hair, and running. (*Apis dorsata* hisses on their comb).
- The ultimate reaction is to sting, embedding barb into attacker. As bee pulls away her entrails pull out as well and she eventually dies. The sting itself releases alarm scents that help other bees orient to the same site. Once a bee has discharged its sting it continues, perhaps even more recklessly than before, burrowing, biting, and threatening flight behaviors.
- Colony defense reaction is attributed to genetic predisposition, temperature (positive relationship) and humidity (positive). Colonies are also more liable to defense response in times of dearth and if their populations are large.
- There is no support for anecdotal ideas that bees "smell fear" on a human observer. Truth is, it is the observers irritable behavior that increases chance of getting stung.
- Avoid stings by gentle handling, slow motions, no perfume, light-colored clothing, appropriate protective clothing.

Georgia Master Beekeeper Lecture Series
LECTURE 8—PHEROMONES

I. General

- a hormone is a substance produced in one part of the body that affects another part
- pheromones are "external hormones"—chemicals from one insect that affect another of the same species; considered to transfer information ("I am the queen")
- allomones are external chemicals that affect other species (ie., bee venom). It doesn't "communicate" in the strict sense.
- these external chemicals (semiochemicals) are released from exocrine glands
- especially important in dark nests, can't rely on vision
- in insects, chemical senses are far more important than visual or acoustic
- in honey bees, 18 compounds or mixtures of compounds act as pheromones, may be as high as 36
- virtually all of the known chemicals are "releaser" pheromones that release or elicit a specific behavior.
- "primer" pheromones exercise a more fundamental level of control, ie., a queen's pheromones that affect worker egg laying, queen production, and foraging behaviors.

II. Worker-produced pheromones

- "Many compounds, few functions." Lots of redundancy.
- Many releaser examples.
- many compounds (16 identified), but few functions (orientation and alarm)
- <u>Nasonov</u>—7 volatile compounds; orientation at nest entrance, swarms, forage marking (especially low-odor resources such as water). Workers expose gland and fan it. Young bees produce very little Nasanov, but it peaks at age 28 days when foraging activity is high. The Nasanov dispersing behavior can be elicited by many odors: empty comb, honey, pollen, propolis, plus one of the queen pheromones, 9-HDA. The pheromone itself induces other bees to expose their Nasanov glands which helps rapid orientation. In swarms, Nasanov works in conjunction with queen pheromones to provide cues.
- footprint pheromone—chemical is unidentified. It is a substrate pheromone, whereas Nasanov is air-borne. Odors left behind at nest entrances and perhaps at flowers. Enhances effectiveness of Nasanov. It is deposited by feet when Nasanov gland is not exposed. Odor tests show that feet are relatively unattractive, so the pheromone is probably produced somewhere else and moves to the feet. Swarms trooping into a new box?
- forage marking pheromone—chemical unidentified. Induces foragers trained to a food source to alight. Probably produced on the dorsal side of the abdomen.
- a sting-produced alarm pheromone, Z-11, acts as an alarm substance, but it also attracts foragers. Z-11 does not not enhance Nasanov. There are four different pheromone-based orientation compounds, Nasanov, footprint, forage-marking, and Z-11. Some may be the same chemicals; for example, footprint pheromone may contain sting components. The forage-marking pheromone is known only from artificial food dishes, not flowers.
- sting-produced alarm pheromone—recruits defensive bees. The famous isoamyl acetate that smells like banana. Released when sting tissues are ruptured. Attracts bees to a previously stung spot.
- mandibular gland-produced alarm pheromone, 2-Heptanone—is a much weaker than isoamyl acetate for recruiting bees; instead it may repel robbers since it is strongly repellent to workers.
- collectively, alarm pheromones alert workers to danger, lower threshold sensitivity to attack, and orient workers to previously-stung sites. However, vision is required to stimulate bees to sting. Heat and humidity increase sensitivity to alarm pheromone

- Why so much redundancy of chemicals? Probably chemicals have very specialized functions. One may make general alarm, but another orients bees to sting sites.

III. Queen-produced pheromones

- "Few compounds, many functions"
- Many primer functions here.
- few compounds/many functions (in workers it's reverse: many compounds, few functions)
- 9-oxodecenoic acid (9 ODA) is "queen substance"
- 9-hydroxy-(E)-2-decenoic acid (9HDA); both are produced by mandibular glands.
- both these are very specific. Isomers are much less active.
- Inhibition of worker ovaries and suppression of queen rearing were first fundamental discoveries of queen pheromones in the 1960s. Until 1990 it was thought that 9 ODA suppressed worker ovary development but that was shown to be false. Instead, workers are probably suppressed by the unidentified queen tergite pheromone probably in conjunction with brood pheromone.
- 9 ODA production levels vary by age: unmated queen <2 days age produces 7 micrograms per day; unmated queen at 5-10 days age produces 108-133 micrograms; mated queen <18 months old produces 100-250 micrograms. Amount of 9ODA is a function of queen age rather than mating or egg laying status.
- Levels of 9ODA decline in older queens which may trigger supersedure—queen replacement and/or construction of queen cells preparatory to swarming (but in swarming the best explanation is not reduced production, but rather reduced distribution in nest).
- 9ODA + 9HDA attract drones, attract workers to swarms, stabilize cluster
- A queen usually has 5 micrograms of pheromone on her body at any one time. Retinue bees (the 'court') remove the greatest portion of this. "Lickers" pick up 10 times more than "antennating" retinue bees. About 1 queen equivalent (1 QEQ ≈ 250μg 9ODA + 150μg 9HDA + other minor compounds) passes through the hive in one day. Workers cannot detect it after 30 minutes when the queen is removed and begin demonstrating first agitation then queen cell construction.
- KSD's MS research demonstrated that increasing the duration of queenlessness had a corresponding decrease in colony defensiveness, worker survival, colony weight gain. Brood production, on the other hand increased, but only due to the presence of laying workers. Nest temperature did not vary according to queenless state but rather the presence or absence of brood (ie., incubation).
- There is anecdotal evidence that queen pheromones increase colony resistance to viruses and diseases.

IV. Drone pheromones

- attract queens to mating sites and organize drone congregation areas (DCAs) and "comets"
- attract other drones to comets?

V. Brood pheromones

- stimulate workers to forage
- inhibit worker ovary development
- elicit nurse bee response to brood. Recall earlier lecture that Jennifer's research suggested that brood survival is best in old comb (sequestered brood pheromones?).

Georgia Master Beekeeper Lecture Series
LECTURE 9—WINTER AND SPRING MANAGEMENT

I. Nest configuration

- Bees move <u>up</u> during winter. Honey and pollen must be above and to the sides
- Dense honey and pollen also insulates
- crowd bees in late summer to get this; in GA we can do this after we take off last honey in June or in August (sourwood). Everything else is bees'.
- need 30-50 lb honey in GA to overwinter
- (from lec. 7, typical colony needs 130-175 lb honey + 33-66 lb pollen = max 241 lb food. Beekeepers in far north or Canada feed 300 lb.
- Depending where you live, you may need one, two, or three hive bodies
- need empty cells in center for clustering
- make sure cluster is centered
- watch queen excluders. Can trap and kill queen

II. Feeding

- feed heavy 2:1 syrup if necessary and throughout autumn and winter
- high fructose corn syrup ok, but beware off-spec types. Can be too acidic.
- emergency feeding if colony is very light. Put food immediately on top of cluster
- only feed 1:1 when natural nectar flows are imminent
- mid-winter pollen substitute may hasten brood production, but be ready to feed syrup!
- only HFCS or cane syrup is acceptable. Brown sugars contain plant pigments, more complex sugars, and other unknowns. Can also cause dysentery

III. Ventilation

- 1.14 grams of water are released for every gram of fat body metabolized; 0.55 grams of water are released per gram of sugar. Metabolism rates and water release soars in Jan and Feb when bees begin rearing brood.
- prop lids up
- lean hives forward
- This was serious problem in Albania with plastic insulation; high rates of chalkbrood

IV. The cluster

- prefer wall-to-wall bees
- clustering begins at 64 degrees
- don't open unless it's above 45 degrees
- always return frames in same order

V. Queen

- queenless colonies will not survive; requeen in fall if population is still high
- many beekeepers make splits in fall because queens are cheaper and there's less swarming

VI. Weather protection

- avoid low spots in yard
- provide wind break
- face south or southeast
- entrance reducers
- mouse guards

- watch snow cover and suffocation
- indoor wintering: once practiced in 19th century, making a comeback in Canada (Canada has great incentive to overwinter now that they don't import U.S. packages; it was also shown to be economically better to overwinter). Temps are maintained at about 50°F. This keeps bees metabolically slow and not flying. Controlled ventilation removes CO_2 and moisture. Red light is necessary to keep bees quiet. Even a flash of light can stir them up and cause losses. Must sweep floor daily. Colonies usually removed in April. There may be a problem with low brood because they were not exposed to increasing daylength.
- in far north, pack colonies: tar paper is dark and absorbs heat. Warmth helps keep colonies dry and lets them move up to new stores and lets them take more cleansing flights.

VII. Health management

- feed Terramycin in fall, any time after honey taken off
- feed Fumidil B if there's a history of Nosema disease
- tracheal mite treatment with menthol or oil patty, but not as effective as in spring
- Pennsylvania survey on overwintering: 53% died in winter of 1995-1996. Beekeepers who applied no medications or miticides lost 72% of their colonies.
  Overwintering death reduction by treatment:
  Oil patties reduced losses by 8%
  terramycin by 15%
  menthol by 7%
  Apistan by 26%
  Fumidil B by 17%
  The greatest survival was by those beekeepers who used terramycin, menthol, Apistan and Fumidil B.
- make sure there's a queen
- Farrar, "Take losses in fall."

VIII. Warm days in winter

- defecation flights and dead bees normal and healthy. . .
- unless dead bees heap up on floor and suffocate (probably a greater problem if there's that many)
- lots of dysentery may be a problem, scrape up sample (or bees in alcohol) and have tested for Nosema
- watch for crawling bees (tracheal mites)
- grain dusts come in, but probably not very helpful
- check if bees alive by pressing ear against super and thumping it; also alerts you to drainage problems

IX. Main spring objectives and paradoxes

- before 20th century, swarming was considered a positive thing. It was thought that colony numbers were the surest way to increase honey yield. Many beekeepers, especially commercial outfits, still embrace this approach.
- This all changed with the work of C.L. Farrar beginning with his 1937 paper *The influence of colony populations on honey production*: within a population range of 15,000-60,000 bees, honey production efficiency increases as population increases. One 60,000 colony makes 1.54 times as much honey as four colonies of 15,000. However, brood production is more efficient in small populations. In 1986 Harbo found the same trends with a population range of 2300-35,000; he also found that larger colonies produce more honey per bee during nectar flow and consume less per bee during nectar dearth.

- the bees' objectives: (1) survive winter dearth, (2) swarm early to let new colony store enough food
- beekeeper's objective: maximum populations before the nectar flow
- in nature, colony population peaks at about 40,000 and honey yields about 50-130 lb; beekeepers can reach populations of 60,000 and honey yields up to 500 lb. This is accomplished by exaggerating bees' natural instinct to hoard honey.
- colonies want to swarm; beekeepers want honey
- beekeepers need young, productive queens; but by discouraging swarming they repress the natural requeening cycle
- Spring management is reconciling these differences. It is a curious blend of *stimulation* and *suppression*.

X. Late winter (Jan-Mar)

- watch feed
- feed Terramycin in February—dust best, patty OK but beware of resistance problems
- treat for tracheal mites in February-March—menthol and/or oil patty
- pollen substitute optional, but watch food stores if you feed it

XI. Early Spring/March (before queens are available)

- For the most part we are *stimulating* at this point.
- combine weak colonies—kill queen of weaker and put together. Newspaper method or simply combine them
- reverse hive bodies or (if single hive bodies) add supers above a queen excluder
- equalize brood and bees (equalize brood, equalize adult populations). Count all brood frames in apiary, divide by colony number, and reapportion. Also, switch colony locations. Don't give a weak colony more brood than it can keep warm.
- sell brood
- remove old menthol and medicated patties

XII. Mid Spring/April (after queens available)

- more *suppression* occurs now as we practice swarm management.
- remember, goal is *uniformly* strong colonies with maximum populations. Nectar flows are only 2-4 weeks away!
- continue equalizing
- sell brood
- requeen/boost weak colonies
- to requeen: order new queen, kill old one, replace attendants with young house bees, insert new queen cage in hive, leave alone for 24 hours, note biting behavior (suggests a free virgin), check for eggs after three days. Alternative methods are push-in cage or requeening with a nuc.
- split strong colonies. Good way to make up winter losses. You can split one hive 50%; this provides a strong split and good swarm discouragement. Or you can make one split from several colonies by combining bees and brood; this provides a split that is every bit as strong as the parents, but it has minimal swarm discouragement because the parents are not being suppressed much. In spring nectar flows there's minimal risk of fighting. It's best to move splits to a new apiary to avoid drift. If not possible, then move parent colony in the apiary (to confuse returning bees) or simply shake in enough bees to compensate for the many that will fly back home.
- cutting cells; this is a very effective way to eliminate swarming. Do it every weekend, shake off bees to see every cell, cut every one out. It is important to maintain this vigil and avoid the point at which there are no eggs (in preparation for swarming). If egg laying ceases, then you don't

know if the colony is queenless and needs one of the cells that you are destroying.

- Clipping queen wings is ok, but a determined colony will still swarm.
- Demaree method—a good way to stop swarming without increasing colony numbers. Put all brood in a new deep super at the top of the hive. Keep queen under an excluder below. Bees go up to incubate brood, thus reducing congestion. But there will be little QMP up there so there will be queen cells. Come back after 7 days and cut them out and check down below too. The removal of brood from the queen is a powerful deterrent to swarming. The brood will emerge and the box get filled with honey.
- hive swarms, give them brood and feed. Requeen, especially if it's a mystery queen.
- boost colonies that swarmed with brood and make sure they have a queen. It may take a while for growth to resume.

XIII. Late spring

- there's two, seemingly opposing, principles about supering: (1) odor of empty comb stimulates hoarding (seems to advocate giving lots of supers) but (2) spreading bees over a big area <u>dis</u>courages hoarding! In other words, lots of supers encourages bees to hoard honey but you can over-do it to the point where surplus space negates any benefit from the odor of empty comb. In practice . . .
- as long as there's bees in top-most super and nectar flow is still in progress, add another super
- when it's late in season, taper off supering or even remove untouched supers to take advantage of the high density principle. Let them fill them out remaining supers completely
- top-supering versus bottom supering. Recent research from Canada says bottom supering not worthwhile at least in weak flows (different results possible in stronger flows). Jennifer replicated over three apiaries and two nectar flows (one strong, one weak) and found same results.
- the only exception to this is for comb honey production. Here the appearance of comb is important. Crowd them a little more to fill out and cap fat combs of honey.

XIV. Equipment considerations

- large combs encourage brood production. Harbo (1988) showed this with four hive designs in which the area of comb was equal but size of combs differed. This is an argument in favor of Langstroth deep hive bodies; however, smaller trees may make this difficult. Many operations use all medium supers.

XV. Cold-weather production

- in Canada with very brief flows they have determined that it is not worth the time of bees to make cappings. So they take off green honey and dehumidify it.

Georgia Master Beekeeper Lecture Series
LECTURE 10—PRODUCTS OF THE HONEY BEE HIVE

I. Honey Composition (p. 871 of Hive & Honey Bee has composition table)

- it is nectar dehydrated to prevent spoilage; moisture range is 12.2-22.9%; above 18.6% it is disqualified in shows, but it is safe from fermentation below 17.1%. Below 15% it is scored down in honey shows because it is too thick.
- bees add enzymes to break sucrose (big molecule) to simpler sugars (smaller molecules); aids digestibility. Glucose and fructose predominate and give it most of its sweetness, energy value, and physical characteristics
- vast majority of sugars in honey are simple monosaccharides—example fructose and glucose
- gluconic acid predominates. Acidity of honey masked by sweetness, but adds to its complex flavor. pH ~ 3.91
- minerals are about 0.17% weight; darker honeys tend to have more minerals.
- enzymes: invertase (one ex. is sucrase) added by bee converts nectar sucrose to glucose and fructose; another is glucose oxidase added by bees which helps keep nectar from spoiling while it is ripening
- protein and vitamins only at trace levels
- granulation may increase as ratio of glucose to water increases (ex. 1.6 no granulation, but at 2.2 complete granulation)

II. Honey's nutritional value

- very digestible; quick energy
- trace pollen in honey, some think it confers resistance to local pollens, but unlikely

III. Honey's medical value

- some antibiotic properties: (1) due to <u>high sugar density</u>, honey has at least (100-18.6%=81.4% sugar solids). The strong interaction between these sugars and available water leaves very little water available for microorganisms. Most bacteria can't live with this little water; however some yeasts can grow when water content exceeds 17.1%. When super-saturated honey is added to bacteria they may die because of osmotic action that dehydrates them. (2) <u>acidity</u>, the pH range of 3.2-4.5 is inhibitory to many microorganisms. For example, the minimum pH for the *E. coli* bacterium is 4.3, *Salmonella* 4.0. (3) <u>hydrogen peroxide</u> is main antibacterial factor. It is produced during an enzymatic process by which nectar is preserved while it is still raw. Glucose oxidase is inserted by bees' and it interacts with glucose to produce hydrogen peroxide which is antibacterial. However, the peroxide activity is only good for diluted honey. But that poses no problem because body fluids re-dilute honey when it is used as a wound dressing; however, such dilution *inhibits* activity from osmolarity! (4) thus, there is great interest in <u>non-peroxide</u>, or *phytochemical* activity. The discovery of this system came when peroxide could not account for all the observed antibacterial action. Best example of this is Peter Molan (Waitangi University) and New Zealand's manuka honey; about half of which is non-peroxidal action. They test honey for its UMF (unique manuka factor) value with 10 being highest.
- because of dilution problems, honey is almost useless as an oral antibiotic. It's best use is in topical applications. There are many anecdotal and clinical reports of honey's excellent performance on burns and skin wounds. Inflammation decreases, sloughing of dead tissue occurs with minimal scarring, and dressings can be removed painlessly without injuring new growth. In many cases, honey dressings work when standard antibiotics and antiseptics do not.

IV. Honey processing

- removing from colonies. Keep clean from grass and smoker flecks
- blower, fume boards, bee escapes
- dehydrating important in humid areas. In Canada flow is so intense and so brief that they remove honey before it is capped, resuper, and artificially dehydrate the nectar into honey. They want bees to spend their time foraging for nectar, not dehydrating.
- warming honey helps it flow and strain easier
- uncapping
- extracting
- heating to reduce aid straining (145° F)
- straining is best done in-line, but free fall is OK if you let it settle 24 hours.
- granulation can be a consumer turn-off. It may also be a problem because the resulting high-water fraction is prone to ferment. The crystals need "nuclei" on which to form. These can be other crystals, dust, pollen, etc. Honey run through pumps granulates more than comb honey; apparently the pump breaks up crystals into fine nuclei. Granulation happens as extra glucose precipitates out. The beekeeper can prevent fermentation by heating honey up to 160° F (careful!) for 4-5 minutes, bottling it hot, then rapidly cooling it. But this will not impede granulation. Honey can be frozen to prevent granulation, but not practical. It is best to store it at room temperature, not in the refrigerator. It is easily reliquified in hot water on a stove.

V. Types of honey packs

- comb
- chunk
- extracted (seven USDA color classes: water white, extra white, white, extra light amber, light amber, amber, dark amber)
- creamed

VI. Honey judging

- moisture must not exceed 18.6% as measured with a refractometer
- granulation
- clarity as assessed with a polariscope, more points lost for beekeeper-added debris (lint) than for natural things (ie., crystals)
- cleanness of jar
- fill level
- flavor
- honey is judged by color class to negate color differences from consideration.

VII. Beeswax

- candles, dipping is old, traditional, and commands best prices.
- beeswax foundation, requires a mill
- cosmetics, lotions, lip balm
- crafts
- weatherproofing (military canvas)
- in WW II used it to insulate wires in missiles

VIII. Pollen

- 24% protein
- 27% sugars
- pollen (on plant) vs. *bee bread* (pollen as moistened with nectar and packed onto corbiculli)
- has lots of indigestible material; but pollen shell can be breached in animal diet studies

- fat content low
- good trace minerals and vitamins
- some risk of allergy and intestinal upset
- pollen diet as a therapy for air-borne pollen allergy is popular folklore but unlikely. Most allergenic pollens are wind-borne, not insect-borne.

IX. Propolis

- collected from plant exudates. These exudates protect the plant from weather and attack from fungi, bacteria, and viruses. These properties are useful to bees and is enhanced by the sticky nature of propolis. It is made up of multiple combinations of flavonoids, phenolics, and various aromatic compounds, generally poorly-soluble in water. Flavonoids especially are known to have various antioxidant, antibacterial, antifungal, anti-inflammatory, and antiviral properties.
- antimicrobial; there are several anecdotal reports of propolis as a good topical antibiotic and burn dressing and even in use against gastric ulcers.
- antiinflammatory
- breath-freshener

X. Venom

- its main components include melittin, apamin, and histamine. It is melittin that is the major pain-inducing element.
- anti-inflammatory, especially believed for arthritis
- most valid use is for treating sting hypersensitivity
- some believe it helps multiple sclerosis (MS) and other central nervous system disorders.
- there's a big popular movement to use venom for numerous health disorders. Called *apitherapy*. Popular in China and eastern Europe but very little scientific interest in America.

XI. Royal Jelly

- produced by worker mandibular glands. Made up of proteins, sugars, and fats in a water base. The fats, or lipis, are highly acidic and are somewhat antimicrobial.
- its consistency is creamy and makes it a good additive for cosmetics.
- any antimicrobial effects are negated when ingested because its high acidity is lost.
- there is relatively little good research to support royal jelly as a medical aid, but it is nevertheless a mainstay of the beekeeping industry in China.

Georgia Master Beekeeper Lecture Series
LECTURE 11—AMERICAN AND EUROPEAN FOULBROOD

I. American Foulbrood

A. Background

- before parasitic mites this was most serious bee disease
- Before G.F. White, AFB and EFB were considered the same disease: "foulbrood." But in White's 1906 USDA publication introduction was the distinction between AFB and EFB, not based on geographic distinctions but rather the areas where they were first investigated scientifically. White was the first to demonstrate that *P. larvae* was the cause of AFB. He fulfilled all of Koch's Postulates: (1) rearing the pathogen in pure culture, (2) reinfecting larvae, (3) reproducing the symptoms, and (4) recovering the pathogen again.
- AFB is present on every continent but not every country.
- today's apiary inspection programs was built on AFB prevention
- in 1990, 7.9% GA beekeepers called AFB the most serious bee disorder they dealt with; the number was much higher in years before mites

B. Disease cycle

- *Paenibacillus larvae* is causative bacterium; changed from *B. larvae* in 1996. Only spore stage can initiate disease; spores last indefinitely
- spores are spread by contact, drifting bees, bee equipment, contaminated honey or pollen.
- drones are slightly less susceptible
- susceptibility decreases with age, and larvae are immune 53 hours after hatch
- LD_{50} (lethal dose required to kill 50% of bee larvae) is 35 spores in one-day old larvae
- spores germinate into vegetative stage after one day in larval midgut
- vegetative bacteria penetrate gut wall (unknown mechanism) and kill larva from *septicemia*—invasion of bacteria in blood
- brood die after they are capped, in prepupal or pupal stage. Spore stage forms again and persists in scale at bottom of cell
- scales are very difficult to remove and remain to start cycle again
- each scale has up to 2 billion spores, and even one spore can infect a larva. Thus, infectivity is enormous.

C. Symptoms

- larvae dull white, tan, brown; at brown stage they're ropy. Ropiness isn't always present
- sunken cappings
- perforated cappings
- odor
- scales; tongue is extended if it died as a pupa

D. Treatment

- if one frame, remove and burn. Feed Terramycin
- if several frames, shake bees onto new frames and boxes. Burn old frames, scorch boxes. Feed Terramycin (see ABJ April 1994 article)
- if pops up again, destroy bees and equipment
- Ethylene oxide fumigation—ineffective on combs of honey
- gamma radiation
- There has been reports from Argentina for several years about Terramycin-resistant *P. larvae*. However, after 40 years of use in the U.S., there was no evidence of resistance. But beginning in

1997 there began reports of resistance in Minnesota and Florida. What could be the cause? Antibiotic extender-patties? So believes Kerry Clark of B.C. inspection service.

E. Prevention

- fall and spring Terramycin treatments (see article)
- avoid contamination; avoid unknown honey. In a USDA survey, 30% of beekeeper-packed honey had spores and 100% of commercial-packed honey had spores!
- genetically-resistant bees: filter out spores from gut, antibiotic properties in brood food, hygienic behavior. However, Terramycin is cheap and effective and this squelched further interest in breeding resistant stock.

II. European Foulbrood

A. Disease cycle

- Schirach in 1771 described a foulbrood, probably EFB, which he believed was caused by "improper food which was consumed by the larvae."
- Cheshire and Cheyne (1885) in England isolated *B. alvei* which they believed to be the causative agent.
- But G.F. White refuted their claim and advanced *B. pluton*, later renamed *Melissococcus pluton*. Aleksandrova (1949) finally satisfied Koch's postulates for *M. pluton* which is now considered the causative bacterium.
- nevertheless, symptomatic EFB may be a complex of other diseases, including *B. alvei*
- larvae infected within first two days of hatch by nurse bee mouthparts.
- multiply in gut and compete with larva for food
- larval appetites increase and nurses normally reject these larvae; thus the disease can go away
- however, if ratio of nurse bees to larvae is high; larvae get "too much" attention. They are fed and continue to live, perhaps even without noticeable symptoms. This is often the case in early spring when bee population is high.
- But when nectar flows begin, more bees shift to foraging duties and larvae get less individual attention, show symptoms, and die. This is why disease flares up during spring buildup and nectar flows. This flareup is also the cure: larvae die and are removed from the colony.
- no spore stage, but bacterium can persist in feces of infected larvae, in brood cells. Disease not as serious as AFB
- nevertheless, it seems to be enzootic in some states (locally and persistently a problem). New Jersey is an example. Nutrition may play a role in colony susceptibility. Pollination units also seem to have EFB at high rates.

B. Symptoms

- discolored, twisted larvae before the capped stage
- brown, sometimes with white tracheae showing through
- only slightly ropy at most

C. Treatment

- Prevent with Terramycin as for AFB
- For an infected colony, give it brood and syrup. Brood compete with infected brood for attention by nurse bees. Syrup stimulates brood production for more competition. Medication may hinder progress by helping infected larvae live. Goal is to physically remove them.
- Requeening may help by introducing a potentially more resistant stock and also by interrupting brood production and giving bees time to clean out cells.

Georgia Master Beekeeper Lecture Series

LECTURE 12—WAX MOTHS, VIRUSES, NOSEMA, SMALL HIVE BEETLE

I. Wax Moth

A. Biology

- *Galleria mellonella* also Old World insect
- in 1990, 52.1% GA beekeepers called it No. 1 pest
- adult females lay eggs in or near bee hives; may prefer to lay eggs in strongest colonies, but this is based on only one study in Louisiana.
- Newly-hatched larvae freely migrate between hives; this too is from one study. Seems counterintuitive and merits repeat study.
- tunnel through combs, eating protein residues: pollen, cast larval skins
- trap young adults, called *galleriasis*
- destroy combs
- burrow into wood and damage it
- cleansing effect on colony? Remember, natural colonies generally more healthy
- this may be argument to replace combs more often

B. Control with PDB

- fumigation with paradichlorobenzene (PDB)
- stack no taller than five hive bodies
- 6 tablespoons of PDB
- cover and seal cracks
- replace crystals as needed and thoroughly air out supers before use

C. Abiotic controls

- penetrate supers with air and daylight
- electronic bug zappers to kill adults
- freeze combs, stack in supers, and seal cracks
- store combs permanently in freezer

D. Control in living colonies

- keep colonies strong!
- well-fitted hive parts. Ex. Tom Sanford in Egypt. Bottom bars rested on top bars below—refuge for moth larvae
- many home-made supers are too shallow. A shallow ought to be 5⅜ inches, but stock lumber is cut to 5-5⅛ width. This makes frames rest against each other and causes problems.

II. Viruses

A. General

- Viruses are pieces of genetic material that parasitize a host cell, pirate its genetic multiplying machinery, and make more viruses
- no vaccines for any honey bee virus
- viruses mutate rapidly and it's difficult to come up with effective vaccines

B. Sacbrood

- dead larvae partially uncapped, or capped cells that remain after others have emerged
- die as prepupae, elongated
- heads curved up and slightly darkened

- skin flaccid and body watery
- adults normally remove infected larvae, so if it shows up it may be a serious infection
- one larva has enough virus to deliver lethal dose to over 1 million larvae
- but symptoms usually present only in late winter, spring, and early summer
- it seems that adults are the reservoirs, but not sure how disease spreads to larvae or why it's only symptomatic in build-up season

C. Chronic bee paralysis (hairless black syndrome)
- bees appear shiny and small because they lose hair
- chewed on by other bees, harassed by guard bees at entrance
- become trembly and flightless after a few days and die
- bees vary genetically in susceptibility, so requeening is a good practice

D. Black queen cell virus
- queen larvae in cells are dead and black
- associated with Nosema disease. Fumidil may help

III. Nosema

A. Biology
- most widespread adult bee disease
- one-celled protozoan *Nosema apis*
- varies in severity across colonies, across apiaries, and across regions
- symptoms vague: crawling bees, disjointed wings, distended abdomens, dysentery
- look at gut. Midgut should be straw-colored with clearly visible constrictions. Infected midgut is white and swollen
- microscopic examination only positive ID
- Spores must be eaten by bees
- in gut, spores germinate to vegetative stage which penetrates gut wall cells and damages them internally
- vegetative protozoans produce more spores in cell; cells shed into lumen, burst, and release spores to infect more cells
- spores in feces persist to spread infection

B. Effects on bees
- reduces lifespan
- infected worker bees can't secrete brood food as well; it affects their mandibular glands
- disease common in times of confinement and brood rearing (early spring); bees can't defecate outside and wintering bees cleaning cells get infected. This may explain why it is less common in the south.
- increases supersedure of infected queens
- slow spring buildup

C. Prevention
- good hive locations
- Fumidil B one teaspoon in two ounces of warm water and add this to one gallon syrup
- feed one gallon (1:1) in spring and 2 gallons (2:1) in fall

IV. Small hive beetle
- *Aethina tumida*, a native of Africa, and member of the sap beetle family. This family is attracted

to fermenting fruit juices.

- Adults are strong flyers and invade strong and weak colonies alike. Adults apparently can eat bee eggs. Lay eggs in irregular masses in cracks and crevices. Hatch in 1-6 days (mode 2-3 days). Larval phase can last 8-29 days (mode 10-14 days). Slower-developing larvae turn into smaller adults. Larvae must pupate in soil. Time spent in soil ranges from 15-60 days (mode 22-30 days). Five generations per year are possible in South Africa. No egg production during winter, and that seems to be the case here too.
- Larvae tunnel through honey, causing it to ferment. The fermented honey is not cleaned up by bees. The larvae may also eat bee brood, but this is not certain. Colonies stop rearing brood and abscond.
- Damaging levels of beetles were first noticed in May 1998 in Florida. In Georgia there are damaging pockets in Savannah, Clinch County, and Jeff Davis County. Many positive apiaries around Atlanta, but none is damaging. May be an effect of soil type.
- soil insecticides, especially the permethrin Gard Star, can kill pupae.
- coumaphos strips were approved January 1999 as an emergency exemption for fluvalinate-resistant varroa mites and small hive beetles.

Georgia Master Beekeeper Lecture Series

LECTURE 13—FUNGI, VERTEBRATES, TOXIC NECTARS, PESTICIDES

I. Fungi

A. Biology

- *Ascosphaera apis* is the disease fungus
- disease first discovered in the U.S. in 1968
- larvae infected when they eat fungal spores; most susceptible at 3-4 days after hatch
- as with most fungi, *A. apis* grows best in cool, damp conditions
- if conditions are right, spores germinate in larva's body
- disease common in cells near edge of brood nest where larvae are chilled; the "chill" can be very slight—just 86° instead of the normal 95° for a few hours
- fungus grows in gut and robs larva of nutrients
- after larva dies fungus grows throughout its body; at this stage the larva swells and fills entire cell—the "chalkbrood" stage
- larva then shrinks to a "mummy"
- sporulation requires both + and - strains; if they are present, black spores form on larva and it turns black to gray; bees remove them and you can see mummies at hive entrance

B. Prevention—deny fungi optimal growing conditions

- avoid cool, low hive locations
- maintain good hive ventilation
- mow grass in front of hives to promote good ventilation
- cull out old, dark combs; they're full of spores and other disease residues
- evidence that certain fungicides work
- Selim's work in 2000: tested comb age, hive humidity, and hygienic. Only hygienic had consistent negative effect on disease expression.

II. Vertebrates

A. Black bears

- no. 1 vertebrate pest in GA beekeeping in mountains and especially in Okefenokee Swamp which overlaps GA's prime honey producing area
- bears destroy bee hives to eat brood, bees, and honey
- electric fences are effective, but bears sometimes learn how to breach them
- This last session, GA legislature considered a bill to allow beekeepers to shoot and kill problem bears after giving notice to Dept. Natural Resources

B. Skunks

- scratch hive entrances, eat adult bees; stings are little deterrent

C. Livestock

- cattle and horses knock hives over
- bulk-feeding bees syrup in open barrels is a bad idea because only the strongest hives get the syrup but, it can be disastrous for cattle; cattle die if they gain access to barrels of syrup and engorge on it

D. Mice

- nuisance in stored equipment and overwintering hives
- control with mouse guards at entrance or rodent bait in storage building

E. Toads

- *Bufo marinus*, giant cane toad exported all over from American tropics.
- Control with boards with nails

III. Toxic nectars

- may see dead and dying bees on bottom board, in front of hive, or on ground at plant
- tends to be very location-specific; certain yards are affected at same time each year
- yellow Jessamine in south GA often coincides with early queen rearing may kill queen cells
- Summer titi, evidence that its pollen causes "purple brood", discolored larvae
- mountain laurel in mountains has toxic nectar; some human tox too.
- privet suspected of making an inedible honey
- only practical solution is to move hives

IV. Pesticides

- incidence of bee kill is generally declining because harder organophosphate insecticides are being replaced with pyrethroids that break down faster
- also pest scouting and integrated pest management (IPM) practices are reducing the number of calendar sprays on crops
- pesticide labels are revised to reflect their degree of bee kill. Some of them specify to not apply in such a manner to kill bees. This gives beekeepers legal basis for compensation in bee kills if misuse can be demonstrated.

A. Gross hive symptoms

- fast kill, dead bees on bottom board and between combs
- heavy layer of dead bees in front of hive

B. Bee symptoms

- agitation, shaking, can't fly, regurgitation, paralysis, death

C. Causes

- no. 1 cause is insecticide spray on <u>blooming plants</u>. This is more dangerous than drift falling on hives
- microencapsulated insecticides (Penncap-M) especially dangerous because bees collect them as pollen grains, store them with pollen at the hive, and it contaminates food for weeks. Causes a very long, prolonged kill.

D. Avoid pesticide kills by:

- correct choice of formulation: generally granules are safer than solutions are safer than dusts are safer than microencapsulated.
- evening sprays of low-residual insecticides. By morning the resident pest population is killed on the plants but the insecticide has degraded enough to be minimal risk to bees
- using contracts (for commercial pollination) that require grower to notify beekeeper of sprays
- Good IPM scouting methods that limit total number of sprays
- keeping good relations with neighboring farmers so they tell you when they're planning to spray. Free honey goes a long way.
- moving hives if pesticides are a persistent problem

E. Rejuvenating poisoned colonies

- soak and clean out contaminated pollen in combs
- replace combs
- feed syrup
- give brood
- check performance of queen and replace if necessary

Georgia Master Beekeeper Lecture Series
LECTURE 14—TRACHEAL MITES

I. Background

- discovered and named in 1921, *Acarapis woodi*
- blamed for the infamous Isle of Wight Disease in England—large scale bee deaths, mostly in winter/spring
- mites spread through western Europe and losses were severe
- This was cause of U.S. Honeybee Act of 1922 to ban all further importations of honey bees to U.S. This ban is still in effect
- USDA found tracheal mites in Colombia in 1980, southern Mexico in 1980, and northern Mexico in 1982. Mites were discovered in southern Texas in 1984 and, through the sale of bees, within months were found in Texas, Louisiana, Florida, New York, North Dakota, and South Dakota.
- Subsequent finds throughout the USA suggest that they were assisted in their rapid spread by trucking mail-order. Results of surveys conducted in the 1960s and the early 1980s on 200,000 specimens from 400 apiaries in USA and Canada demonstrated that the mite was not established before 1984.
- It took less than five years for the mite to spread to most of the major beekeeping states in the USA. State and provincial quarantines may have slowed the distribution of the mite, but only a few isolated areas remain free of infestation.

II. Biology

- microscopic mite
- Has a clear association with the European honey bee, *A. mellifera*. However, other host species are reported, namely *Apis cerana* and possibly *Apis dorsata*. Reports from India indicate that tracheal mites have caused losses in *A. cerana* colonies similar to the North American experiences with European colonies.
- *Acarapis woodi* is present on every continent except Australia.
- *A. woodi* lives only within tracheae; *A. dorsalis* is in the dorsal groove on the thorax, and *A. externus* is on the underside of the back of a bee's head.
- female mite grabs hair of passing bee and crawls toward CO_2 exiting at spiracle
- host-seeking mites prefer young bees in first four days of life. Mites will feed on immatures if forced in laboratory, but this is not natural
- they distinguish old from young bees by age-related changes in bees’ cuticle. Cuticular hydrocarbon ratios change as bee ages
- Makes sense to prefer young bees—more time to complete your own life cycle
- inside tracheae, female pierces the tracheal wall and sucks blood of bee
- infested tracheae are heavily scarred and have lots of debris. Secondary infections very likely
- Female begins to lay eggs in 1-2 days.
- Females lay 5-7 eggs over 3-4 days. Eggs hatch after 3 to 4 days.
- One generation of mites per host is common but a second generation is possible in longer-lived bees in the fall and winter.
- Mite goes through a six-legged larval stage, followed by a nymphal stage, and finally develops into an adult in 11-15 days.
- Adult males are slightly smaller than females and generally emerge one day in advance of the females emerging.
- Female mites lay almost one egg a day, each of which is about two thirds the weight of the female herself. This would be equivalent to a 150 pound woman having a 100 pound baby! The females have an unlimited supply of bee blood to feed upon and produce such large eggs.

- Sibling mites mate. This is common in mites and causes apparently no inbreeding depression
- Mated daughters leave trachea of host bee and seek a new host. Adult males apparently do not leave the host in which they are born.
- colony mite levels grow from late summer, through fall, winter, and drop off in spring. There is a true ebb and flow, unlike Varroa that grows until colony is dead.
- Tracheal mites infest all three types of bees in a colony, including young queens, drones, and workers.
- Drifting drones are important in mite dispersal between bee colonies. Workers, however, being numerous, are of prime importance when examining the effects of tracheal mites on bee colonies. Queens, due to their longevity, may serve as a reservoir for mites, but more than two mite generations within a queen seem unlikely as infested tracheae become increasingly damaged with mite feeding over time.
- The effects of mite parasitism on queen performance or supersedure are unknown.

III. Pathological effects on bees

- Tracheae that are normally elastic and flexible become stiff and brittle. Tracheae of severely infested bees have brown crust-like lesions and are obstructed by mite debris and numerous mites in all stages of development.
- This mechanical damage decreases the oxygen supply to the tissues.
- damage flight muscles, crawling
- damage nerve ganglia near tracheae, crawling
- atrophy worker brood food glands
- elevated bacteria in blood

IV. Chemical Control

- concentrated menthol only product registered by EPA
- most effective in spring treatments which goes against our hunches
- 2-ounce packet. Put on top bars at top of hive if temps are 60-79; put on bottom board if hotter. Menthol melts and bees are repelled by it. Below 60 degrees it evaporates poorly and control is minimized
- leave on colony for 12 weeks max.
- In Europe Folbex VA (bromopropylate). The miticidal fumes were generated by igniting a paper strip that had been treated with potassium nitrate (saltpeter) and bromopropylate. The smoldering strip is hung in the top of a standard-size colony with the hive entrance plugged for 30 minutes.
- Formic: good efficacy of three weekly 40-ml treatments of 65 percent formic acid liquid on paper pads. Treatments were effective in temperate zones in spring or fall.
- perforated bag delivery (ie., Medhat)
- gel pack has had packaging problems

V. IPM Concept

- Integrated Pest Management—integrating many methods to manage pest populations
- grew out of the pesticide excesses of the 1950s and 1960s, Rachel Carson's *Silent Spring* was terrible scientific reporting but was sensational and awoke public awareness
- economic threshold precedes economic injury level
- implies that some levels of pest are tolerable, this also requires an educated buying public that will tolerate spotted apples and wormy corn.
- implies some way to measure pest population, so sampling techniques is a big part of this research.
- treat only when pest reaches economic threshold

- the goal is to lengthen the interval between treatments as much as possible. This allows conservation of susceptible genes in a pest population.
- use as many methods as possible to limit pest populations; economic thresholds, pesticide rotation, management, mating disruption, genetics, beneficial insects (importations, refugia, cover crops)
- pesticides remain the most important pest control measure, and the only control in emergency situations

VI. Sustainable Agriculture
- a development of the 1990s
- key word is "sustainable" which means pest management practices that can last a long time.
- In sustainable agriculture there is an emphasis on employing natural processes that already occur on the farm in order to boost productivity. One example is the shift from fence row-to-fence row cultivation in preference to leaving field edges feral. This encourages refugia for beneficials and forage for pollinators.
- An example in apiculture is Jennifer's work on comb age. By keeping young combs in hives we may increase overall colony health and productivity.
- Total reliance on synthetic pesticides is considered non-sustainable because (1) pesticides become obsolete when pests become resistant to them, (2) companies may stop production for economic or regulatory reasons, (3) concerns for non-target organisms, and environmental and human health

VII. IPM in practice, pesticide economic thresholds for tracheal mites
- Eischen & others estimated 30% of bees infested for stationary colonies honey production colonies northeastern Mexico.
- Bach estimated the economic threshold for colonies rented for multiple pollination contracts in the Pacific Northwest to be only about 15%, half that of the stationary Mexican colonies.
- These numbers suggest that the stress of multiple moves for commercial pollination lowers the economic threshold

VIII. Chemical rotation
- because they kill acutely, selection pressure is very high for pesticides
- chemicals kill by different <u>modes of action</u> (the way they work)
- so, hasten pest resistance by rotating chemicals. Use menthol one year, another the next
- Once formic acid gets approved this will be an important recommendation in the U.S.
- in Canada, formic acid. Very caustic.
- There are others in Europe, ie., apitol, a systemic fed in syrup.
- growing interest in botanicals—neem, thymol, peppermint

IX. Tracheal mite control by management
- newly-emerged bees are mite-free; we can use this fact as an IPM strategy
- since newly-emerged bees are clean, anything that drains a colony of its old bees reduces mite levels.
- swarming does this naturally; in nature, colonies free to swarm have reduced mite levels
- splitting also does this. Old bees fly back to parent, new bees tend to cling to combs, new queen stimulates new brood.
- The prolific egg laying by a young queen tends to reduce the average mite load by increasing the number of bees in relation to the number of young migratory female mites.

X. Control with vegetable oil

- tracheal mites prefer bees in the first four days of life; distinguish them by cuticular hydrocarbons
- in a 1987 paper Gary & Page found that vegetable oil in lab beakers reduced tracheal mite infestation in young bees; artifact of a laboratory study for genetic resistance in bees
- a follow up study showed that oil does protect young bees from host-seeking mites
- vegetable oil seems to confuse host-seeking mites by masking their signature cuticular hydrocarbons
- 1970 paper by Wilson, extender patties for Terramycin, fewer trips to the apiary; Pfizer never added instructions to the label and beekeeper use was small
- Delaplane paper in 1992 tested oil, menthol, oil+menthol, or nothing as experimental check
- show data slide. Oil as good as menthol; oil + menthol best (demonstrates IPM concept of many methods)
- Calderone & Shimanuki tested oil of peanut, canola, sunflower, and soybean—no differences
- There may be a seasonal effect and/or geographic effect? Most literature supports spring treatments which confer protection up to the following spring. But, in contrast, Calderone & Shimanuki found lower levels in May from treatments applied previous autumn.

XI. Control with bee breeding

- since some colonies survive tracheal mites, bee breeding is a real possibility for control
- Tracheal mites are natural parasites, so some resistance exists. Populations ebb and flow, in contrast to Varroa. This gives us plenty of raw material to breed with.
- early studies looked at stiffness of spiracle hair—no effect
- Gary & Page showed that different lines of bees having lesser and greater susceptibility to mites can be selected from a common population. Different bee lines are simultaneously exposed to a uniform source of mite-infested bees. By breeding from the highest and lowest lines (bi-directional breeding) they showed that the differences had a genetic basis.
- Queens of Old World Buckfast stock were imported in 1990 from Great Britain to the United States and Canada for testing. In comparisons with three other stocks, Buckfast bees had low mite prevalences during the 1-year test and had other desirable traits such as good honey production and survivability. Brother Adam spent his life developing Buckfast bees. High levels of mite resistance and productivity
- Other stocks donated by U.K. beekeepers did not perform well (Roger Morse's importation).
- Autogrooming; young resistant stock bees apparently are more effective at cleaning migrating mites off themselves. Autogrooming can occur as part of a "grooming dance" which occurs more frequently when mite infestation is high. Differences in cuticle chemistry, hairs around spiracles, or grooming among nestmates are not major determinants of resistance.
- Resistant bees cause little or no reduction in fecundity of the mites which infest them.
- there may be endemic pathogens of tracheal mites. Virus particles found in Scotland that are absent from California.
- It is easy for beekeepers to propagate resistant stock. Just don't treat with acaricides, accept natural rates of colony loss from parasitism, and then propagate only from the best colonies. This has been shown to improve mite resistance in the population of selected colonies.

XII. Antibiotics

- Sammataro found that colonies treated with Terramycin-treated oil patties "appeared healthier and more populous".

Georgia Master Beekeeper Lecture Series
LECTURE 15—VARROA MITES

I. Background

- worldwide the most serious pest of honey bees
- originally confined to the eastern honey bee *Apis cerana* on which it causes only minor damage on drone brood
- in late 19th century *A. mellifera* were moved into southeast Asia where they contacted varroa
- colonies were freely transported between Asia and Europe, and by 1964 varroa mites were found on *A. mellifera* in Russia
- Today they're on every continent except Australia. Not in Hawaii, found in Devon England in April 1992.
- found in U.S. in October 1987 in Wisconsin, probably from colonies recently moved from Florida
- genetic markers of U.S. varroa populations suggest they came from South America which in turn came from Japan.
- varroa found in Georgia in 1989; by 1991 they were well-dispersed in south Georgia and occurred in four north counties. Today they are state wide.
- varroa is transcontinental except for areas of Nevada and northern Canada
- in 1987 Canada closed the border to U.S. queens and packages. Severe, but temporary hardship for U.S. producers.
- Today queen and package producers have robust business from replacing lost colonies.
- In 2000 it was determined that *Varroa jacobsoni* is probably more than one species. The species now considered to be the virulent form spread around the world is newly-named *V. destructor*.

II. Profound effects of varroa

- varroa is one of the mileposts of U.S. beekeeping: on par with the 1622 introduction in Virginia and Langstroth's inventions
- loss of feral honey bees has profound ecological consequences. Native pollinators may rebound (*Bombus*)
- Raises question whether *A. mellifera* is indeed a wild, non-domesticated animal if they rely on humans for survival
- Pollination suffers because: (1) high density of plants need (2) high density of pollinators, and (3) only honey bees have sufficiently large populations to do this.
- thus, free pollination is a thing of the past
- economic consequences: in short term, many beekeepers quit business because control is expensive. Many oldsters quit, the "pre-" and "post-varroa" generation gap.
- However, in long term the economics may be good for beekeepers. Fewer beekeepers and fewer feral colonies mean higher per-colony yields. Because of varroa, there is a world-wide honey shortfall coupled with increased demand.
- shortage of pollination increases demand for hive rentals. A new phenomenon for GA and a new market for beekeepers

III. Life history

- lives on both adult and immature honey bee; only eggs and larvae are unaffected. This helps explain the rapid collapse of a colony.
- once a colony is infested, it usually dies within six months (GA) to five years (Finland), depending on latitude. They seem to collapse quicker in warmer latitudes (Northern hemisphere) where brood rearing is nearly constant. In colder latitudes (Northern hemisphere) they grow more

slowly.

- adults are *phoretic* which means they hitch-hike on adult bees. They spread to colonies on drifting or robbing bees. Speculation about getting on bees at flowers and for temporary phoresy on other insects such as predatory hornets.
- adult mites can subsist on adult bees by feeding on hemolymph at intersegmental membranes
- reproduction is limited to brood cells. In *Apis cerana* they reproduce only in drone brood but in *mellifera* they can reproduce in worker brood too; this partly explains their seriousness on *mellifera*.
- they are haplo-diploids just like bees. Non-mated females can only produce male mites.
- a *foundress* female enters a brood cell about 20 hours before it is sealed. She immediately buries herself in the brood food at the bottom of the cell. They have ventral peritremes that poke through the food and let them breathe. They are trapped in this position unless the feeding activity of the larva frees them.
- bee larva molts to the elongated prepupa and at this point the mite begins feeding on the hemolymph of the bee.
- the first egg is laid about 60-70 hours after the brood cell is sealed. Usually laid on the cell wall. First egg is male, the rest female. Foundresses lay 5-6 eggs, but usually only the first four (1 male, 3 female) have enough time to complete development. However, mortality of nymphs reduces net reproduction to about 1.5 new daughters per foundress. When multiple foundresses invade a cell, reproductive efficiency declines and eggs are resorbed.
- Protonymph feeds and molts to a deutonymph which feeds and molts to an adult. Total required development time is 10-15 days which is very brief for mites generally.
- mating of siblings occurs in cells.
- when the bee emerges, foundresses and daughters leave with it. Males and any immature females stay behind and die.
- this is the phoretic stage. Females may immediately invade another brood cell, but those that first feed on adult bees have better reproductive success.
- as competition for available brood cells increases, more than one foundress invades a cell. This reduces reproductive output. Thus, reproductive rate grows geometrically in early infestations but tapers off in later, heavily-infested colonies. However, damage to the colony is severe by that point and collapse is common.

IV. Effects on bees

- varroa is considered the most serious beekeeping problem worldwide.
- considerably mechanical injury to immature bees.
- 6-25% reduction in body weight
- 34-68% reduction in longevity
- many late summer bees do not survive all winter (those that make up the cluster)
- 15-50% reduction in hemolymph proteins and total hemolymph volume
- increases in blood bacterial count
- varroa seems to trigger latent infestations of acute bee paralysis virus
- wing damage and shortened abdomens
- bees with 5 or more mites developing in their cells have very small chance of surviving, or if they do there will be visible wing damage.
- by the time the beekeeper sees visible damage the infestation is severe.
- brood sometimes takes on disease-like symptoms (parasitic mite syndrome). There is no well-defined pathology. The brood may be infected with secondary pathogens or merely neglected.
- spotty brood, dwindling populations, but not necessarily a reduction in brood area; it’s as if the bees try to compensate.

- death in summer and fall is the norm for varroa (spring for tracheal)

V. Detection methods
- remember, mites are in both brood and adults
- simple observation—see them on adults or on broken burr comb, especially drone cells. Infestation can be severe by the time you see this
- alcohol shake
- mites per brood cell
- ether roll
- bottom board inserts

VI. Conventional control and its problems
- in U.S., Apistan is only registered control. A synthetic miticide impregnated in a plastic strip
- active ingredient is fluvalinate
- activity discovered in France and Israel
- originally liquid Mavrik, soaked on plywood strips; this was the method used in Florida
- Apistan is better formulation, time released for constant delivery over 56 days.
- one strip per five brood combs
- do not treat during nectar flow
- right now the U.S. industry depends on synthetic miticides. This makes industry vulnerable. What if Wellmark decides to drop product?
- Resistance was detected in Italy in early 1990s; seemed to spread from this focus rather than pop up independently elsewhere. Resistance showed up in 1997 in South Dakota and Florida and now suspected in California and Arkansas
- in Canada, formic acid is registered, and maybe soon in the U.S. It kills mites in cells, but overall activity is inferior to Apistan
- In January 1999 GA got a section 18 for coumaphos for fluvalinate-resistant varroa and hive beetles.
- formic due August 1999
- much interest in botanicals, but they too are toxins and prone to resistance, non-target tox, etc.

VII. IPM and European economic thresholds
- thus, IPM is of utmost importance in Varroa management
- registration of formic acid would help—let us rotate pesticides
- one key to IPM is treatment thresholds—only treating when it's economically, and biologically, warranted
- but, there's no treatment thresholds for North America. In Europe, they think 5,000 mites in a "normal" colony is the economic injury level. At 10,000, the colony is doomed
- >800 on bottom board inserts reflects more than 2000 mites in colony and is probably a workable economic threshold
- in Europe, colony takes 3-4 years. From beekeeper experience, these figures are clearly not right for North America

VIII. Economic thresholds for North America
- KSD'sproject with Dr. Mike Hood
- An ether roll of 15-30 and insert levels of 60-180 seem to be a workable economic threshold for the southeast.
- threshold data probably vary by region and should be developed on a regional basis; however recent data from Delaware, Nebraska, and Ontario suggest that we're all pretty much the same.

IX. Secondary diseases

- Terramycin increased body weight of adults and immature bees
- antibiotic increases body weight of parasitized bees, regardless of miticide treatment
- body weight loss is common with varroa and associated with reduced bee longevity
- may increase honey yield numerically (maybe not significantly)
- thus, simultaneous antibiotic treatment with acaricide is prudent

X. Control by breeding

- some exciting work at Michigan State University and Baton Rouge bee lab
- selecting for grooming behavior, hygienic behavior, short post-capping period, and non-reproduction in mites
- in 1995, two crosses had non-reproducing mites. Ie., mite numbers <u>decreased</u> in time. Don't know responsible factor, but mites from non-reproductive brood had lower sperm counts in their spermatheca.
- in Europe, they also select for incompatible brood. Cut squares of brood from various stocks, tie them into a comb of brood, subject them to same colony, pull out and count mites. Which square has the fewest mites? Does this mean reproduction would be reduced in colonies of this stock?

XI. Control by management

- drone comb trapping
- only effective at times of year when they're raising drones
- only effective in lightly-infested colonies
- very labor-intensive
- brand new idea, varroa bottom board screen. Mites drop off bees and cannot get back on and starve.

Georgia Master Beekeeper Lecture Series
LECTURE 16—AFRICANIZED BEES

I. *A. mellifera scutellata* in its home turf

- tropical Africa—perpetual weak nectar flows, lots of mammal and bird enemies, extreme weather
- found on savannahs, woodlands, and in mountains up to 2000 m where snow lasts up to a week
- rather than make a huge winter food supply, these bees focus on reproduction. Combs may be entirely brood
- to make up losses from weather or enemies, populations simply swarm a lot
- colonies migrate, unlike European *Apis*
- lives in open or in unusual cavities: holes in ground, small voids

II. *A. m. scutellata* in South America

- European *A. mellifera* were imported to S. America about same time as in N. America
- however, in 300 years, *A. mellifera* had failed to colonize S. America as they had in N. America
- in 1956, Warwick Kerr imported 26 queens of *A. m. scutellata* into Sao Paulo state in Brazil where they flourished and eventually colonized all of tropical S. and Central America. They accomplished in 40 years what European *Apis* failed to do in 300.
- spread from point of origin at 100-300 miles per year extremely variable behavior—highly defensive (except when small or a swarm); better honey producers in weak flows, poorer producers in good flows; do not tolerate commercial pollination conditions (moving on truck); cannot be close to people or livestock; use huge smokers and layers of clothing; liability; keep hives on individual stands
- in Latin America, new-generation beekeepers are happy with them. Management methods totally different. Set out empty boxes, get filled with swarms, harvest honey

III. Hybridization Controversy

- How did progeny of 26 queens overwhelm millions of European *A. mellifera*?
- Extreme advantage of tropical genes in the tropics
- colony usurpation by AHB swarms and queens
- drone parasitism—AHB drones disproportionately drift into European colonies. Causes negative feedback loop in EHB drone production
- disproportionately high drone production by AHBs
- In honey bees, drones typically fly farther from colonies than do queens; this helps avoid inbreeding
- However, AHB drones fly shorter distances from the home colony than do EHB drones; thus, EHB queens encounter higher number of AHB drones
- study at U. of Florida found mitochondrial DNA of AHBs in central America relatively unchanged from *A. m. scutellata* in Africa. This supported a non-hybridizing hypothesis.
- however, others found data supporting hybridization. Generated *African* versus *Africanized* debate

IV. AHBs in the U.S.

- first swarm in Hidalgo, Texas in October 1990
- today they're in Texas, AZ, NM, CA, PR, and St. Croix
- many states have an action plan that calls for limited quarantines, requeening, and queen marking

V. Potential spread in U.S.

- in southern Argentina, they find zones of pure African, hybrid, and pure European, more-or-less following latitudes.
- trend seems the same in Mexico and Texas
- temperature is probably not the most important factor in spread. Note differences between Taylor 1985 map and map in HHB text p. 46
- however, distribution in U.S. may be limited by more by Varroa and fire ants! A surprise to the experts
- plus, high densities of Europeans in Mexico and Texas are slowing spread
- hybridization is very obvious: AHB diagnostic tests show more and more intermediates

VI. What to do about AHBs

- AHB vs. EHB will probably become a moot point as hybridization increases
- African genes will probably introgress into our populations
- average defensiveness of bees may increase
- requeening will become more common
- bee breeding industry may shift north. We in south may have to shift requeening and other management practices into later season
- liability risks
- individual stands, more clothing, larger smokers, white veils
- biggest thing is to discourage ordinances that ban beekeeping. Worst possible scenario! It removes beekeepers which are our only source of gentle European stock. Already happened in Gwinnett County

Georgia Master Beekeeper Lecture SeriesL
LECTURE 17—HONEY BEE GENETICS AND BREEDING

I. Cytology

- chromosomes are made up of DNA
- some DNA exists in cytoplasm of cell, in mitochondria; only inherited maternally
- females have 16 pairs=32 chromosomes; diploid
- males have 16, one member of each pair; haploid
- these reside in the cell nucleus
- a gene is a sequence of nucleotides that make up a section of DNA
- genes exist in alternate forms called alleles; there are dominants and recessives
- genes carry the instructions for protein synthesis for all parts of the body
- another molecule, tRNA, transcribes or “translates” the nucleotides in genes; messenger RNA (mRNA) then moves into the cytoplasm and collects the appropriate nucleic acids, in their correct sequence, to make the protein coded by that particular gene.
- genotype is the genes an individual carries
- phenotype is the characters that are expressed by the individual
- mitosis happens when cells divide as in organismal growth; the chromosome set simply replicates and splits
- meiosis happens only in germ cells (gametes); here the chromosome number is halved. In honey bees this happens only in females. Males are already haploid; they are “flying gametes.” In diploid animals meiosis allows the union of gametes to restore the full 2N number of chromosomes.

II. Homozygosity vs. heterozygosity vs. hemizygosity

- multiple alleles of the same genes is heterozygosity—heterosis or hybrid vigor
- homozygosity is high frequency of same alleles—inbreeding depression
- hemizygosity is having only one allele of a gene—only possible in drones

III. Sex determination

- sex determination in Hymenoptera is more than gene dose; it’s actually under genetic control
- parthenogenesis is development of individual from unfertilized eggs. It is very common in Hymenoptera, and the rule for males. Males arise from unfertilized eggs laid by either a worker (which cannot mate) or a queen (which can withhold sperm voluntarily).
- Parthenogenesis that produces normal 2N female individuals happens naturally about 1% of the time in workers. This is very common in cape bee in which queenless colonies can persist for a long time with laying workers.
- Dzierzon in 1845 published his theory that male bees are from unfertilized eggs. For a long time it was thought to be a simple matter of gene dose.
- But, in fact there is one gene for sex determination with multiple alleles.
- heterozygosity for this gene produces a female
- hemizygosity and homozygosity produce males, but homozygous males are normally destroyed by workers. It is possible to rear these triploid males in the laboratory and use them in instrumental insemination to produce triploid individuals.
- as homozygosity (inbreeding) increases, there are more and more skipped cells of brood because of increase in homozygous males that are eaten
- thus, drones result only from their mother’s unfertilized gametes; they are exclusively the genetic expression of their mother. This means that drones do not have a father, but they do have a grandfather.

IV. Genetic organization of colony

- queen mates with 7-17 drones and retains their sperm
- about 4-7 million sperm migrate from the lateral oviducts into the spermatheca over a period of 40 hours.
- the sperm are fairly well mixed which means a colony will, on average, express continuously the genetics of all drones mated to the queen. (If, on the other hand, the sperm were layered one could expect the colony to express different traits over time.)
- a colony is made up of subfamilies that share the same mother but different fathers
- thus, there are sub-sisters and super-sisters
- as the number of matings increases, so does the genetic variability of the colony. This is good for the colony because it increases genetic plasticity and ability to weather difficulties.

V. Breeding problems

- multiple matings make colony-level selection difficult; which subfamily has the desired trait?
- instrumental insemination makes possible fewer, even one, matings so that colony level selections can be more precise. But, this is a high-tech procedure
- selection must be quantifiable as much as possible—count stings for a defense test, frames of brood, pounds honey produced. Beekeepers reluctant

VI. Breeding designs

- Inbred-hybrid breeding—takes advantage of heterosis. Inbred parent lines are selected for their crossing ability with other lines, not necessarily their own desirable characteristics. They, in fact, show inbreeding depression. Midnights and Starlines are two popular examples of this
- Closed population breeding—"closed" in that an identifiable population exists from which to select, but heterozygosity and constant selection is encouraged. Select an initially superior stock. Daughters from breeder stock are inseminated with 10 random drones from the population, and superior daughters are used to replace mothers. This takes 35 breeder colonies to maintain at least 85% brood viability for at least 20 generations.
- Maternal selection/Open mating—this is the most common method of "breeding." Extremely casual or even accidental, but it works! Breeder grafts from those queens he "likes." The good ones even carefully select their drone mothers. Put drone foundation in drone mother colonies and place them in the mating nuc yard.
- Maternal selection has been shown to work in honey production.KSDsaw evidence for it in Mississippi with burr comb. The overall gentleness and productivity of our bees further attests that this method of selection imparts significant genetic changes on our bees.

Georgia Master Beekeeper Lecture Series
LECTURE 18—BEEKEEPING IN NORTH AMERICA AND GEORGIA

I. Continental Outlook
- California is biggest beekeeping state and most diverse: pollination, honey, almonds, queens and packages
- Minnesota and Dakotas biggest honey producers, vast monocultures of clover and alfalfa
- overwintering in Texas, queens and packages
- cranberry pollination in New England
- cranberry pollination in Nova Scotia, feral plants that grow after forest is cleared
- orchard crop pollination in Michigan and Pacific Northwest, cherries, pears, apples
- Florida overwintering, honey production, some queens and packages
- hobby beekeepers everywhere
- Georgia is the major supplier of queens and packages in the east

II. Important honey plants of North America (excluding minor buildup plants)
- clover is ubiquitous and most important
- alfalfa important, especially in west whee it's grown for seed
- star thistle and fireweed in western mountains
- canola in Canada, and some in Georgia too
- blackberry and other brambles in west and southeast
- acacia and mesquite in southwest
- soybean in midwest, west Tennessee, and Arkansas
- black locust and basswood in central south

III. Beekeeping Regions of Georgia
- southeast in Okefenokee Swamp is major honey production area
- a bit north is the major queen and package belt
- central and southwest GA is pollination of squash, watermelon, cucumbers, also honey from cotton
- west central highlands have sourwood
- piedmont is blackberry, tulip poplar, brambles
- northeast mountains is sourwood, many GA beekeepers migrate to mountains
- northwest mountains is more like piedmont; not much sourwood

IV. Commercial queen production
- graft one-day old larvae
- put them in starter colonies made up fresh each day so nurse bees are young
- after 24 hours put them in cell finisher colonies; two-story, queenright, with an excluder
- after 10 days, put cells in mating nucs
- cage them after mating flights

V. Package production
- one crew hunts queen and sets out frames of bees (put queen back in hive)
- shaking crew shakes bees; beware of shaking during nectar flows because it can kill bees (rupture honey stomachs)
- add queen, syrup can, vacuum clean, staple health labels

VI. Organized Beekeeping in Georgia

- The Georgia Beekeepers Association meets February and October
- There are 11 regional associations, some of which host beekeeping shortcourses and special education efforts for schools, flower shows, etc.
- GA Dept. of Agriculture is responsible for inspections, health certificates, and quarantines. By law, every beekeepers is supposed to register.
- The Cooperative Extension Service has a county agent in every Georgia county. A large supply of bulletins, leaflets, newsletter, and videos.
- The Perry National Fair has a huge bee display
- annual Beekeeping Institute
- the UGA program is one of 14 state university bee research programs in the country; before Dr. Delaplane was Dr. Al Dietz (ret. 1994) who was here since the 1970s.

Georgia Master Beekeeper Lecture Series
LECTURE 19—BEEKEEPING AROUND THE WORLD

I. Beekeeping in the Tropics

- *Apis mellifera* and *A. cerana* are primary bees
- sun is directly overhead at midday during two seasons of the year; thus, there can be two buildup seasons.
- brood rearing is more tied to forage availability
- many small, continuous flows rather than few big ones
- absconding more common as local flows diminish
- queens wear out more quickly
- tend to have less disease problems; less winter confinement
- colony populations tend to be smaller
- day's heat stops nectar secretion so bees forage heavily at early morning or even by moonlight
- beekeeper must keep constant watch on food stores
- overheating prevention is more important
- a permanent apiary water source is necessary
- varroa grow year-round, but in many tropical areas varroa is less serious than in temperate areas. Probably because the mites themselves are genetically different and/or the bees can out-race the mite. Also absconding helps.
- wax moths are acute threat especially in weak colonies that can't cover combs
- bait hives to catch swarms common. Beekeepers watch flying migrating colonies, learn the common routes, and set out bait hives to catch swarms. Sometimes use very cheap boxes that won't be stolen, and transfer combs into a Langstroth hive when swarm moves in.
- transfer wild colonies in trees or rock crevices into standard hive
- *A. cerana* begins swarm preparation while colony is very small. It is difficult to get them large enough to produce much. They also abscond.

II. Top-bar hives

- not a good track record with Langstroth hives
- the top bar hive can be made from local materials and extreme precision is less important
- it is easier to harvest a few combs at a time
- no need to store combs and protect them from wax moths. Just consume comb, honey and all.
- can be hung from trees to deter thieves and escape predators
- can be hung from trees to catch swarms

III. Beekeeping in Albania

- heavy reliance on manual labor and animal power
- in transition from traditional skeps to Langstroth
- woven basket, dowels through it, plastered in cow manure, sheath of straw

IV. New Zealand

- strong government support programs
- strong market for apitherapy products, especially manuka honey
- thixotropic honeys are pressed from combs
- lots of kiwifruit pollination

V. England

- non-standard hives, including Dadant
- British National Hive, square design
- WBC hive, similar to old Langstroth with a lap-board sheath over super
- strong hobby interest
- local honey promoted
- hobby naturalists
- heather honey

Georgia Master Beekeeper Lecture Series
LECTURE 20—BIOLOGY OF POLLINATION

I. Flower structure

- flower is a type of plant reproductive structure
- corolla to protect sexual parts
- male parts are stamen, made up of filament and anther
- female part is pistil, made up of ovary (may contain carpels) of one or more ovules (potential seed), attached to a style, with a sticky stigma on top
- a *perfect* (or hermaphrodite) flower has both male and female parts; ex. apples, blueberries
- an *imperfect* (male or female) flower has only one or the other; ex. squash
- flowers can occur singly, or as *inflorescences* such as clover
- A *berry*, such as tomato, has a fleshy outer wall surrounding one or more fairly small seeds
- A *pome*, such as apple, has a fleshy outer wall surrounding a tough core with seeds.
- A *drupe* or *stone* fruit, such as peach, has a fleshy outer wall surrounding one stony seed.
- With *aggregate* fruits, such as strawberry and raspberry, many pistils develop together as a single mass.
- If pollination is poor in ovaries with more than one ovule (such as berries and pomes) or in multiple neighboring ovaries (such as aggregate fruits), tissue develops only around those ovules that are fertilized. This causes misshapen tomatoes, apples, and strawberries.

II. What is pollination?

- pollination is the transfer of pollen from male parts to female parts of the same or different flower
- there are about 250,000 species of flowering plants, many of which need pollination
- there are many types of pollinators:
  - √ abiotic: wind, gravity, rain
  - √ vertebrate: birds, bats, monkeys
  - √ invertebrate: spiders, mites, beetles, thrips, moths, and bees
- of invertebrates, bees are the most efficient and important pollinators; they are probably most important pollinators of all
- *pollination* stops at transfer to stigma; *fertilization* is accomplished after pollen tube grows and male gametes fertilize ovule
- pollen incompatibility often manifests by inability to germinate on stigma or complete growth

III. Pollination Requirements

- self-sterile plants cannot fertilize themselves; they require *cross-pollination*—pollen from another plant; ex. is rabbiteye blueberry and apple. In these orchards, grower must interplant a main variety and a pollenizer variety. Must be close so pollinators can move pollen between them and bloom at same time.
- there are cross-compatible and cross-incompatible varieties; plant catalogs provide charts
- self-fertile plants can be fertilized by their own pollen, but they are not always self-pollinating; ex. is sunflower. Thus, even these may need pollinators.
- with *monoecious* plants, both sexes of flower are on the same plant; ex. is cucumber
- with *dioecious* plants, there's only one sex of flower on a plant; ex. is kiwifruit
- monoecious and dioecious plants generally require cross-pollination
- *parthenocarpic* fruit sets without fertilization. Ex. is seedless watermelon. However, even these crops benefit from pollinators. Seedless watermelon needs pollination to trigger seed and tissue development; seeds abort shortly thereafter.

IV. Ecology of pollination

- bees and plants need each other, but both operate selfishly
- for plants, nectar is a costly reward to lure pollinators
- goal is to have pollinators visit many flowers. There's two ways to do this:
    - √ make all flowers have just a little nectar
    - √ have most be empty, but have a few (5-8%) with a lot of nectar
- for the bee, flight and foraging is costly and must be balanced against the benefits of nectar and pollen
- optimal foraging theory predicts that an animal will forage in a way to optimally balance energy cost and income
- some of its predictions:
    - √ Bees that have just visited highly-rewarding flowers fly shorter distances before visiting another flower than do bees that have just visited less rewarding flowers
    - √ Honey bees fly several miles to forage if necessary, but they prefer to forage close to home
    - √ Bees tend to forage in straight lines which decreases the chance of revisiting empty flowers
    - √ Animals forced to forage in resource-poor habitats spend more time at each food site than do animals in rich habitats

Georgia Master Beekeeper Lecture Series
LECTURE 21—CROP POLLINATION I

I. Value of bee pollination, macro view

- production of honey, queens, and package bees pales in comparison with the economic impact of bee pollination of food plants
- bees also:
  - √ pollinate food plants for wildlife
  - √ pollinate plants that control erosion
  - √ pollinate rare or endangered plants
  - √ pollinate plants that beautify our surroundings and increase property values
- 12 species of food plants—banana, barley, cassava, coconut, corn, millet, potato, rye, rice, sorghum, sweet potato, and wheat—provide early 90 percent of the world's food supply, and <u>don't require bee pollination</u>. Thus, on the surface, bee pollination looks superfluous.
- But, when you consider the huge quantities of legume forages that are converted into meat and dairy products, bee-pollinated crops are essential to the standard of diet expected in developed countries.
- One well-worn, and probably accurate, estimate says that bee pollination is directly or indirectly responsible for one-third of our food supply. This is more accurate for diets in developed countries.
- in the U.S., 130 crop plants need bee pollination
- these crops are low-acreage, high-value crops like blueberries, watermelon, cantaloupe, kiwifruit, cranberries, apples, pears, strawberries, and cucumbers
- bee-pollinated crops make the difference between eating for survival and eating for pleasure. Imagine life without almonds, hamburgers, blueberry muffins, butter, ice cream, cheese pizza, strawberry shakes, pickles, or apple dumplings
- low-acreage, high-value bee-pollinated crops pump millions of dollars into local ag economies: Alma, Georgia (blueberries); Ellijay (apples); Moultrie (cucumbers); the Rio Grande valley in Texas; the San Joaquin valley in California
- in the U.S., value of honey bee pollination ranges from $1.6-14 billion per year
- these values determined by "what if" scenarios calculating value of lost production if there were no bees [see bar graph for individual crops]
- in Canada value of honey bee pollination is about $443 million, and about 47,000 colony rentals occur each year
- world-wide, the acreage of bee-pollinated crops is increasing; for example, in Canada 17 percent of available acreage is devoted to bee-pollinated crops.
- thus, we are asking more and more of our available pollinators. Are there enough bees to do the job? This has raised interest in bee conservation (covered in final lecture)

II. Value of bee pollination, micro view

- *good* bee pollination means, depending on fruit and flower structure: percentage of fruit pollinated (called *fruit set*), or percentage of ovaries per flower pollinated (important in compound fruit like strawberries)

- good bee pollination increases:
  - √ fruit set and yield
  - √ fruit size
  - √ earliness of ripening (means big $$ for fresh crops, blueberries; south GA growers are always eager to beat their Michigan competition for the premium early crop)
  - √ sweetness
- In Washington and British Columbia, experimenters increased honey bee visitation in cranberry with a synthetic bee attractant and realized a 41 percent yield increase with a $3,564 per acre increase in revenue

III. Advantages of honey bees as pollinators

- honey bees are the most important insect pollinator world-wide
- reasons for this:
  - √ huge populations; in one overnight delivery an orchardist can increase the bee population in his orchard by millions
  - √ honey bees are generalists and visit many kinds of crops; thus, a "one bee for all purposes" approach often works
  - √ they are highly manageable and predictable
  - √ they tolerate highly-automated, mechanized handling

IV. Disadvantages of honey bees

- because they are generalists, they are not very *efficient* pollinators (defined as probability that one bee visit will pollinate the flower). This is a problem with crops with specialized flower structure (blueberry, tomato). It's less of a problem with flowers with more open structure (apples).
- thanks to their recruiting behavior, they excel at finding the best resource in an area. If that's not your crop, you're in trouble. The bees will ignore your crop and forage on the richer "weed." This is a real problem in south Georgia where squash blooms at the same time as gallberry.

V. Bee flower visiting behaviors

- *probing* with mouthparts is usually for nectar. Even probers can get pollen on their bodies
- *scrabbling* for pollen is brushing anthers with forelegs to rake pollen off them
- *buzzing* the flower is specialized behavior, absent in *Apis*, in which bees vibrate flowers to release pollen. Important in specialized flowers like tomato, *Nandina*, and blueberry.
- for this reason, bee species vary in their effectiveness on certain crops (ex., Cane's blueberry data)
- many bees rake pollen off their hairs and onto their scopae. Pollen that misses this grooming behavior is sometimes very likely to pollinate subsequent flowers. Such places are pollen *safe sites* (for ex., under the chin). In this way, even a nectar forager can pollinate.
- generally though, pollen foragers are superior pollinators

VI. Minimum hive strength standards

- bees should blanket top of 6-10 frames
- 4-6 combs well-filled with brood, preferably young brood
- healthy 2-story hives usually meet these criteria
- for one-story hives, check a little more to make sure you're getting minimum strength hives

VII. Managing honey bees for pollination

- hives moved at night when bees are indoors. Big operations palletize bees and load them mechanically. Net the whole load, wet them (if it's really hot), and drive non-stop.

- naive bees are the most efficient pollinators because they have not habituated to competing bloom. Get this by:
  - √ don't keep hives at site of crop year-round
  - √ moving in bees after about 10% of crop is already blooming
- standard hive density is one hive per acre. However, this varies with crop. In poor pollination conditions (bad weather, unattractive crop, competing bloom) grower needs many more hives to increase bee visitation through competition. This goes against inclinations of grower.
- honey bees forage best within 300 ft. of their hives; so, place hives at 500-ft intervals so foraging radii overlap
- if you can't reach field interior, concentrate hives at field center; this forces bees to forage deeper into field
- pheromone-based bee attractants (Bee Scent [Nasanov], Fruit Boost [9ODA]) may help in suboptimal conditions:
  - √ if field interiors are muddy and inaccessible
  - √ if crop is naturally unattractive to bees (pear, cranberry)
  - √ to counteract competing bloom
  - √ if cool weather diminishes effectiveness of available bees
  - √ if sudden warm weather compresses bloom and overwhelms available pollinators
  - √ grower's first priority must be the bees themselves

Georgia Master Beekeeper Lecture Series
LECTURE 22—CROP POLLINATION II

I. Causes of pollination problems

- unattractive crop (should plant breeders make crops richer bee forages?)
- competing plants
- no pollenizers
- poor pollenizer bloom overlap
- poor orchard layout (pollenizers remote)
- too much crop and too few bees

II. Contracts

- number of hives
- location
- duration of stay
- minimum strength standards
- property liability
- sting liability
- pesticide agreement
- fee and payment plan

III. Apple

- The flower has five stigmas that join into a style that leads to the ovary.
- The ovary has five divisions, each with two ovules, which means a fully-pollinated fruit has ten seeds.
- Surrounding the style are 20-25 pollen-bearing stamens.
- Each flower cluster has a primary bud called the *king bloom* that opens first and produces the best fruit
- At least 6-7 ovules must be fertilized; if fewer are fertilized the fruit will be misshapen, small, or may not stay on the tree until harvest.
- Most apple varieties require cross-pollination with another compatible variety. Many varieties show a degree of self-fruitfulness, but not enough to allow solid-block plantings. So, orchardists must interplant main varieties with compatible pollenizer varieties.
- The bloom periods of the main and pollenizer varieties must <u>overlap</u>. To optimize pollination, plant both early- and late-blooming pollenizers so that the main variety blooms in between. That way, ample pollen will be available for the early-blooming king bloom on the main variety, and if frost kills the king blooms, late-blooming pollenizers will provide pollen for the remaining flowers.
- Some apple varieties have sterile pollen. These varieties willingly receive pollen from other varieties and produce fruit, but they cannot be used as pollenizers.

IV. Apple Orchard Designs

- Bees prefer to work up and down rows rather than across rows.
- With plan 1, every other tree is a pollenizer; this maximizes the number of pollenizers, but it is practical only if there is a market for the pollenizer. All other plans compromise some degree of pollination efficiency in favor of convenience at harvest.
- With plan 2, every third tree in every third row is a pollenizer; this ensures that every tree of the main variety is next to, diagonal to, or across from a pollenizer on one side.
- Plan 3 calls for a solid planting of the pollenizer every fourth row; this leaves one row of main

variety by itself and is only practical if the pollenizer has market value.

- Plan 4 calls for two pollenizer rows next to four rows of the main variety; this is the least efficient design.

V. Blueberry

- There are three general types of blueberry commercially grown in North America: highbush, lowbush, and rabbiteye. Lowbush is a spreading, ground-covering blueberry grown in northern states and Canada. It develops from a fertilized seed but spreads as a single clone with underground growth to cover a large area. Lowbush blueberry grows feral and quickly colonizes burned or cleared ground.
- Highbush and rabbiteye blueberries are upright, individual plants well-suited to intense orchard management. Highbush varieties are grown throughout much of the United States; rabbiteye is grown in the south. Northern highbush genes have been incorporated into southern *Vaccinium* spp. stocks to produce southern highbush varieties that ripen earlier than rabbiteye. Earliness of ripening is important in the premium-priced fresh market
- The blueberry flower usually occurs on racemes at the ends of branches. The pinkish-white petals join to form a tubular corolla that hangs downward. There are eight to ten stamens at the base of the corolla surrounding a long style that extends beyond the anthers and to the opening of the corolla. At the end of each anther is a pore through which pollen is released during the period of stigma receptivity. Nectar is produced at the base of the corolla. If the flower is not pollinated within the first three days of opening, fruit-set is unlikely. If the ovary is successfully fertilized, it ripens 2-3 months later into a berry containing up to 65 small seeds. Well-suited for buzz-pollinators.
- Highbush varieties are largely self-fertile, but cross-pollination sometimes increases number of seeds per berry, fruit-set, fruit size, and speed of ripening.
- Rabbiteye varieties are largely self-sterile and require cross-pollination with a suitable rabbiteye variety. Cross-pollination with other rabbiteye varieties improves fruit-set, size, and earliness of ripening.

VI. Blueberry orchard designs

- You want to increase the chance of a bee visiting two or more varieties during the same foraging trip.
- If you want equal numbers of two varieties, plant them according to plan 1.
- If you want ⅔ of variety A and ⅓ of variety B, plant them according to plan 2.
- If you want three varieties, use plan 3.

VII. Watermelon

- Plants are monoecious—that is, each bears both male flowers and female flowers. A few varieties bear perfect flowers and male flowers.
- Each flower is about 1 inch (2.5 cm) diameter and pale green or yellow. The petals unite to form a tubular corolla enclosing three stamens that surround a short style and a three-lobed stigma. There are nectaries at the base of the corolla.
- Flowers open within two hours of sunrise. Pollen is usually released before the flower opens, but it stays on the anthers in sticky masses unless it is removed by insects. Stigmas are receptive as long as the flower is open, but receptivity is highest between 9:00-10:00 AM. Flowers close in the afternoon, never to reopen even if they are not pollinated.
- Watermelon flowers are attractive to bees for nectar and pollen, but flower density is low and bees are easily distracted to richer resources.
- Watermelon is self-fertile, and a female flower is pollinated equally well by pollen from a male

flower on the same or different plant.

- The pollen grains are sticky and insects are required to transfer pollen to receptive stigmas. Each stigma needs at least 1,000 pollen grains spread evenly over the three lobes to form a large, well-shaped fruit.
- Seedless, triploid watermelon varieties also require pollination. Pollination triggers seed formation and fruit development, but seeds abort shortly thereafter.

Georgia Master Beekeeper Lecture Series
LECTURE 23—BEE CONSERVATION

I. Is there a bee shortage?

- lots of anecdotal evidence from home gardeners, growers, county agents. "Where are all the bees?"
- In southern Arizona, winter losses in a population of feral honey bees increased from 13 percent in 1991-1992 to 61 percent in 1994-1995.
- One expert estimated that "90 percent of the [honey] bees that once lived in hollow trees and buildings in the Northeast [U.S.] have died in the past one to five years"
- near Sacramento CA, 75% of colonies visited in 1990 no longer existed in 1993, and all surviving colonies had Varroa
- Numbers of beekeepers in the U.S. dropped by about 20 percent between 1990-1994
- Number of honey-producing colonies in Georgia has dropped from 111,000 in 1990 to 75,000 in 1998
- non-*Apis* bees may be rebounding, but there is still 300 years of competition to overcome
- plus, acreages of pollinated crops is increasing. Thus, bee conservation is timely

II. Basic needs of bees

- shelter
- protection from predators, parasites
- dependable food supply, especially during reproduction season

III. Habitat conservation

- Bees prefer open, sunny habitats. Warm, sunny nest sites help speed colony development. This is especially important for annual nests of solitary bees or bumble bees and may explain why soil-nesting bees often dig nests in open patches of bare soil.
- habitat edges are especially species-rich. Bees do better in open, sunny habitats with an abundance and diversity of food plants than in flower-poor, shaded woodlands.
- The diversity of bee species in a habitat increases as the diversity of nectar- and pollen-bearing plant species increases. Unfortunately, monocultural agriculture promotes the exact opposite.
- Focus conservation efforts on sunny, open undisturbed meadows, field margins, sun-drenched undisturbed patches of bare soil, roadsides, ditch banks, and woodland edges.
- no compacting with heavy machinery, draining, herbicides, mowing, or plowing.
- Plan bee sanctuaries for the long term. As the years go by you can expect increasing numbers of plant and bee species in these undisturbed sanctuaries. But one catastrophic event—plowing for example—can undo years' worth of progress.
- It's good to keep habitat in a mid-stage of succession with high number of species. A climax forest is usually bee-poor. Thus, periodic mowing is in order.

IV. Bee Pastures

- Goal is improved bee nutrition to encourage high bee numbers either by attracting them to the area, increasing the number nesting in the area, or by increasing their reproductive output.
- Long-term payoff of perennial pastures may be good, especially since non-honey bees tend to nest near where they were reared the previous year
- Measured against the background of normally-occurring food plants, the installed pasture must be "large enough" and "rich enough" to make a difference—variables knowable only by research
- For solitary bees, only need food during active season.
- For honey bees, need abundant food at least sometime so they can store it up

- However, for bumblers which persist for 2-4 months, steady food income is important, especially when they are reproducing in mid to late summer
- in southeast, a mid-summer dearth is common
- key is to identify voids in bloom calendar, and fill them in with desirable plants
- plants must not be noxious, invasive, or compete with crop
- candidate plants in Georgia. Canola (very early), Vitex, Purple Coneflower, Sunflower, Abelia
- perennials are better forage plants than annuals. In the long run they are more reliable producers of nectar and have lower cost of installation when spread out over their years of service.

V. Bigger is better

- large, uninterrupted corridors best, rather than many fragmented habitats
- In Poland, Banaszak (1992) recommended that for a normally functioning agricultural landscape, the area of land in cultivated fields or mowed meadows should not exceed 75 percent of the total area. The remaining 25 percent should be left as bee sanctuary.