An Introduction to Bee Biology

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Part 1: Overview of Bees

There are an estimated 30,000 bee species worldwide. The vast majority of these species are solitary and do not produce honey or large nests with young, and therefore do not exhibit colony defense (Buchmann, 2005).

When one typically thinks of a bee, the species that typically comes to mind is the western honeybee, *Apis mellifera*. The genus *Apis* is comprised of eight species. *Apis mellifera* is comprised of 24 different races. The most common commercial production race is *Apis mellifera ligustica*, commonly referred to as Italians. This race is known for its high rate of honey production and its gentle nature, making it a favorite in apiaries, or commercial bee production facilities.

Italian bee working in its hive. Photo by Zach Huang.

The majority of bees that one sees outside of a hive are workers (sterile females). A typical honeybee colony consists of 50,000-60,000 sterile workers, 500 to 1000 drones (fertile males) and one queen, the only fertile female in the colony and mother of the entire population of the hive (Bishop, 2005).

Some people confuse bees with wasps. Bees tend to be vegetarians and are generally hairy, whereas wasps tend to be carnivorous and hairless (Buchmann, 2005). The vast majority of BeeSpace activities center around the western honeybee, *Apis mellifera*.

Bees or wasps? These European Paper Wasps show the hairless bodies typical of wasps. Photo by Zach Huang.

Part 2: Bee Anatomy

Like all insects, the body of a bee consists of three regions, the head, the thorax, and the abdomen.

The head houses two compound eyes, which are used for distance vision outside of the hive, as well as orienting the bee's flight relative to the sun. Each eye consists of 3000 to 5000 visual processing units called ommatidia. The eyes do not perceive shapes clearly but identify color well. A bee's compound eyes are receptive to ultraviolet light, but less receptive to reds. Bees recognize blue, yellow, white and black.

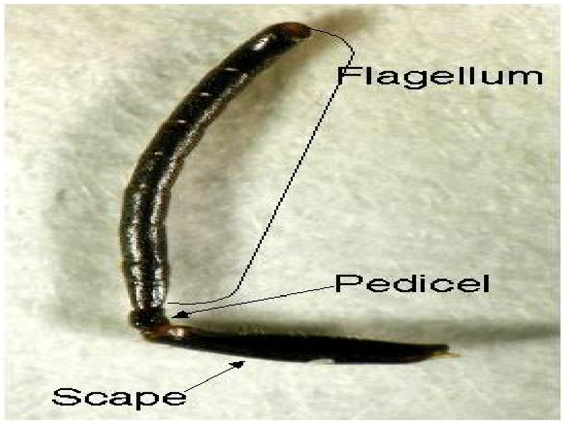
Worker head showing distinct compound eyes, antennae, and chewing-lapping mouthparts. Photo by Zach Huang.

You can experience the visual world of the bee, seeing the world as they do, at [B-EYE: The world through the eyes of a bee].

Simple eyes, called ocelli, are found near the front and top of the head. Ocelli register intensity, wavelength, and duration of light. At dusk the ocelli estimate extent of approaching darkness, causing the bees to return to their hives.

Top of the head, showing the three ocelli. Photo by Zach Huang.

Antennae receive and analyze highly volatile substances that are responsible for odor and taste. Antennae also perceive vibrations and movement of air, sounds, temperature (the five terminal segments of the flagellum) and humidity (the eight terminal segments of the flagellum) .

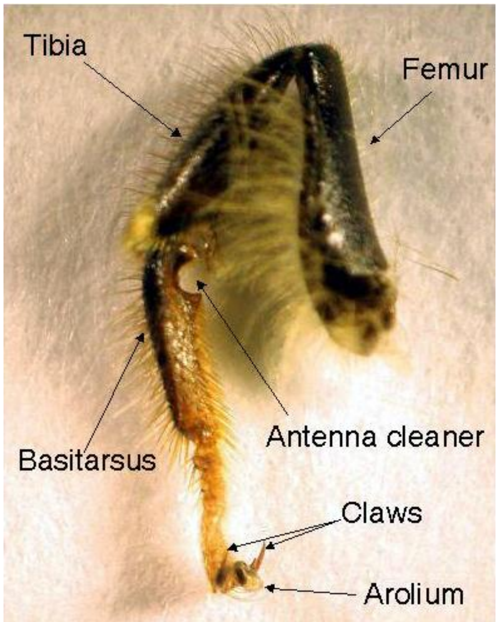


Worker antenna showing its three regions.Photo by Zach Huang.

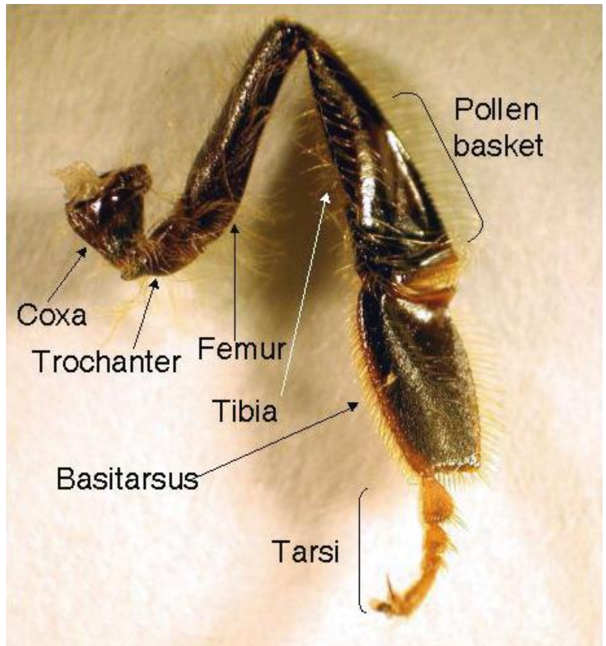
The thorax includes the legs and the wings. At the end of each leg are structures called tarsi, which taste what they touch (more specifically, they detect quality and concentration of different chemicals). Claws and arolia (soft pads between the paired claws of each leg) combine to provide an effortless hold on both smooth and rough surfaces (Apiculture: Know the Bee, Manage the Apiary).


Paired claws and suction pad-like arolium at the end of a bee's leg. Photo by Zach Huang.

The first (frontmost) pair of legs has a notch in its first terminal segment for cleaning antennae. The middle pair has spines on one side specialized for removal of masses of pollen brought to the hive. The third (hindmost) pair of legs each possess a pollen basket (corbicula) in which the pollen mass is kept during transportation from the flowers to the hive. The lower side of this pair of legs also possesses a row of stiff hairs, collectively called the pollen comb.

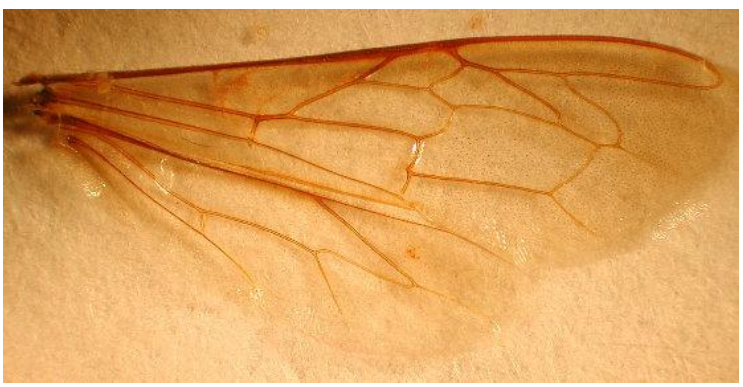


Front leg showing antenna cleaning notch.



Hind leg showing pollen basket and comb.

Wings of each bee species vary in their venation (vein) pattern. The slight differences in *Apis mellifera* wing venation can be useful in differentiating between races. The forewing is always larger than the hind wing. The front and hind wings are held together (coupled) by approximately 20 small hooks located along the front margin of the hind wing. Bee wings can beat nearly 200 times per second.

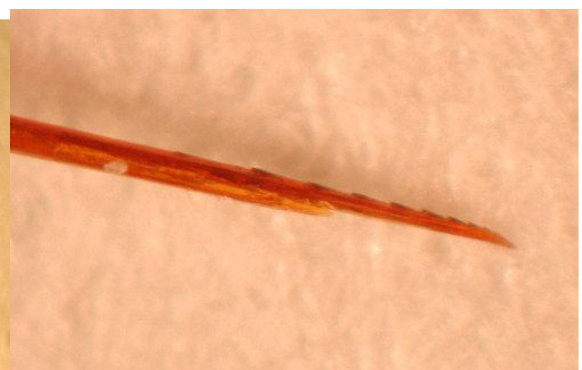

Coupled fore- and hindwings. Photo by Zach Huang.

The abdomen consists of seven visible segments. The first is very narrowed and makes up the petiole (waist) of the bee, while the seventh segment of workers (sterile females) and queens includes the sting (Apiculture: Know the Bee, Manage the Apiary). Wax glands on the underside of worker abdomens secrete the wax that makes up the honeycomb.

Wax scales secreted by the four pairs of glands on the underside of a worker's abdomen. Photo by Zach Huang.

The sting is a modified ovipositor, so it is found only in females. When pushed from the end of the abdomen, it locks into position at a right angle to the base. Muscular abdominal plates then push the stinger into the flesh. The sting has a scalpel-sharp point, with two serrated retractable rods (lancets) on the sides. The venom bulb is positioned at the top of the sting. It continues to pump venom 30 to 60 seconds after breaking off from the abdomen of the worker bee.

Sting with attached venom sack. Photo by Zach Huang.



Close-up of sting showing barbs that prevent easy removal. Photo by Zach Huang.

Up to half of the venom stored in the bulb consists of melittin, a chemical substance that causes pain, impacts blood vessels, and damages tissues. In response, the body of the stung organism produces histamines, which cause localized itching, redness and swelling. Photolipase A2 and hyaluronidase contribute to the swelling and spread of the toxin. Additionally alarm pheromone is released at the time of the sting, stimulating further defensive response in the workers. Each worker dies shortly after stinging her victim because the sting and part of the digestive tract are left are left at the site of the stinging incident (Bishop, 2005).


Tearing away of sting and part of digestive tract. Photo by Zach Huang.

Part 3: Bee Life Stages

Typical of the most advanced insects, bees exhibit complete development or complete metamorphosis. This means that the young and the adults look very different and the diet of the young and the adults typically differ, preventing the parents from competing with their offspring for resources. The life stages are egg, larva, pupa and adult. Development from egg to new worker typically takes two (Tales From the Hive, 2000) to three weeks (Bishop, 2005).

Egg
The eggs are sometimes described as having an appearance similar to sausage-shaped poppy seeds. Each egg has a small opening at the broad end of the egg, the micropyle, that allows for passage of sperm. Hatching takes place three days after egg laying (Jean-Prost, 1994).

Larva
The larval stage lasts eight to nine days. Upon hatching, the larva is almost microscopic, resembling a small, white, curved, segmented worm lacking legs and eyes. For the first two days, all larvae are fed a diet of royal jelly. Beginning the third day, worker larvae are fed honey, pollen and water, while the larvae destined to become queens continue to receive royal jelly throughout their larval lives. Regardless of whether the larva is male or female, it molts five times during its larval stage (Jean-Prost, 1994).

Workers caring for larvae. Photo by Zach Huang.

Care of the larvae is constant. Each larva receives an estimated 10,000 meals during this stage. Larval weight increases 5 1/2x during the first day, 1500x in six days (Tales From the Hive, 2000).

Larval stage durations vary:
5.5 days for queens (fertile females),
6 days for workers (sterile females), and
6.5 days for drones (fertile males) (Jean-Prost, 1994).

Pupa

The pupal stage is a stage of massive reorganization of tissues. Organs undergo a complete reorganization, while body changes from the wormlike larval body shape to the adult body shape with three distinct body regions. Pupation periods vary: queens require up to 7.5 days, drones require14.5 days, while workers require 12 days (Jean-Prost, 1994).

Queen and worker pupae. Note the larger size of the queen pupa. Photo by Zach Huang.

Adult
Adult bees are either workers (sterile females), queens (fertile females), or drones (fertile males). A typical honeybee colony consists of 50,000-60,000 sterile workers, 500 to 1000 drones (fertile males) and one queen, the only fertile female in the colony and mother of the entire population of the hive (Bishop, 2005).

Worker (left), drone (middle) and mature queen (right). Photo by Zach Huang.

Workers provide virtually all of the efforts required to maintain function within a hive. During the latter part of their life, each will travel up to two miles in search of pollen, nectar and water. Each worker typically goes on ten food gathering journeys per day, each lasting approximately one hour. This heavy workload takes its toll; each worker lives for about a month prior to wearing out (Tales From the Hive, 2000).

Immediately after emerging from its pupal cocoon within one of the many brood cells, it immediately goes to work. During the first four days of its adult life, each worker is cleaned and fed by the other bees while its body hardens and it begins to produce substances in various glands. Activities during the next seventeen days include cleaning, feeding larvae, manipulating wax, processing honey, guard duty and air conditioning the hive by fanning. Any of these activities can be done at any time based on the needs of the colony.


Workers caring for a queen larva within its queen cell. Photo by Zach Huang.

On day 21 the worker leaves the hive, and works for another 20 days, bringing in pollen, nectar, water, and propolis before taking its final flight away from the hive and dying (Hooper, 1976).

Pollen, a plant protein source for the young, provides nitrogen, phosphorus, amino acids, and vitamins essential for development of these vegetarians. Pollen is collected in pollen baskets (corbicula) on the workers' rear legs.

Nectar, obtained from floral nectaries deep within flowers, provides a pure carbohydrate source for all stages. Each workers fills her honey sac within her digestive system, increasing her weight by up to one half. Upon arrival at the hive, the worker regurgitates the contents of the honey sac to the younger workers within the hive. These younger workers receive the nectar, which is processed by enzymes within their honey sacs, and tipped into storage cells where it ripens for five days. At this point the substance becomes honey, and the cell containing it is capped for storage. Nectar from 5 million flowers is required to produce a single pint of honey (Tales From the Hive, 2000).

Water is essential for hydrating all of the individuals within a hive and cooling it throughout the year. Approximately five gallons are required to hydrate and cool the colony each year (Hooper, 1976). Propolis, the final substance brought into the hive, is also called "bee glue." It is a plant resin used to build and maintain hives.

Queens can be distinguished from workers by their longer tapered abdomens and greater size. Queens have the longest lifespan of all of the bees within the hive. Their major role centers around egg laying to insure the vast numbers of individuals required to maintain a hive.

Mature queen with eggs. Photo by Zach Huang.

Colonies will make a new queen if the original is ailing or infertile. This is done by producing a special wax cell around 7 or 8 fertilized eggs, the oblong armored incubator looks somewhat like a peanut. Eggs and larvae are slathered with royal jelly (vitamin-rich hormonal goo made by workers) for a two-week period, after which a new queen emerges. The first new queen to emerge stings all her sisters within the specialized wax cell (all of whom are potential queens) and may kill the original queen (her mother).

Five to fifteen days after emergence from her pupal cocoon and cell, the young queen flies off, mating with as many as ten drones over a several day period (Jean-Propst, 1994). She will store the sperm from these matings in a spermatheca for the duration of her life, never to mate again.

Spermatheca storing sperm from matings. Sperm may be viable up to four years. Photo by Zach Huang.

She returns to the hive and begins laying up to 1,500 eggs per day. Queens typically lay several hundred thousand eggs over their lifetime (Tales From the Hive, 2000). After two to four years, the queen uses up all of her stored sperm and begins producing unfertilized eggs, which give rise to drones. Usually the workers raise oneor more queens from the last of the fertilized eggs to replace the new queen (Jean-Propst, 1994). To maximize hive productivity, honey farmers replace the queen annually or every other year (Bishop, 2005).

Drones are the male bees within a colony. Drones can be distinguished from workers and queens by their large size, rectangular abdomens, large conspicuous eyes, and noisy flight. All drones lack a sting, and have more eye facets than a worker (6,000-7,000 vs. 3,000-5,000).

Worker (left) and drone with reproductive structures protruding. Photo by Zach Huang.

Drones result from unfertilized eggs. They emerge 24 days after the egg is laid. Drones are capable of extracting honey four days after emergence, but prefer to be fed by workers. Unlike workers (sterile females), drones can't fly well, don't gather food for the colony, don't clean, don't secrete wax, and do not care for young. The role of the drones is largely to fertilize new queens. A group of drones follows each virgin queen on her early flights. Several males will mate with each virgin queen while flying, dying immediately after mating since his reproductive organs and the end of his abdomen break off, temporarily plugging the end of the queen's reproductive tract and abdomen

Assuming all goes well, drones typically live for about 50 days. If there is a fertile female in residence, the workers may withhold food from the drones or gnaw off the drones' wings and legs. By fall, all of the males and male larvae are evicted from each colony (Bishop, 2005).

Part 4: Africanized Bees (Killer Bees)

In the 1950s, Brazilians tried to jumpstart their honey industry using European bees. However the European bees didn't adapt well to the Brazilian climate. African bees, much better adapted to the environmental extremes of many of the areas interested in commercial beekeeping, were imported in hope that they would become a commercially viable species. African bees tend to be 10% smaller than European bees. Additionally, they are 25% lighter, they reproduce earlier, and they have a shorter lifespan.

Africanized bees at the entrance of a hive. Photo by Zach Huang.

At the time, the prospective beekeepers were unaware of the fact that African bees tend to be much more fierce, dominant, and aggressive than the European bees. In addition, African bees tend to be nomadic, which meant that they readily left manmade hives, moved into the jungles and establishing their own colonies away from human habitation.

Behaviorally, African bees tend to be offensive, rather than defensive, when other organisms come into close proximity of their hives. In fact, the defensive response of a single bee causes a rapid response so that suddenly and severely the organism may experience attack by hundreds of bees. Africanized bees may pursue invaders for hours after the organism under attack has left the immediate hive area. Though the venom is virtually identical to that of European bees, the intensity of the attack and the volume of venom that the invading organism experiences led to the popular press designating Africanized bees as "killer bees."

These aggressive bees rapidly took over European bee colonies with three years of their initial Brazilian introduction. In contrast to the European bees, Africanized bee honey harvest is unpleasant and may be dangerous, while the yield is unreliable.

Africanized bees expanded their range to Venezuela in1973, Mexico in 1986, and established some colonies in the U.S. by 1990. They now can be found in New Mexico, Arizona, Nevada, and California (Bishop, 2005).


Foraging Africanized Bee (Tucson, Arizona). Photo by Zach Huang.

Part 5: Bee Parasites/Competitors

Bees have several parasites/competitors. The species making the greatest impact on honeybee populations include bacteria and mites. Each organism and its impacts are briefly outlined below:

Bacteria
Parasitic bacteria make their most significant impact on young larvae. The diseases most commonly caused by these bacteria are known as American foul brood and European foul brood.

American foul brood is caused by *Bacillus larvae.* Infected colonies containing brood (larvae and pupae) often die. Because the bacterial spores remain viable for decades, it is essential that measures be taken to prevent infection in the first place. Spores are transmitted to the larvae by adult workers, who clean and feed the larvae. Nurse bees often remove some infected larvae though the decomposed larval remains, which are typically loaded with spores, prevent the workers from being able to effectively clean out the brood cells containing the infected and dead larvae.

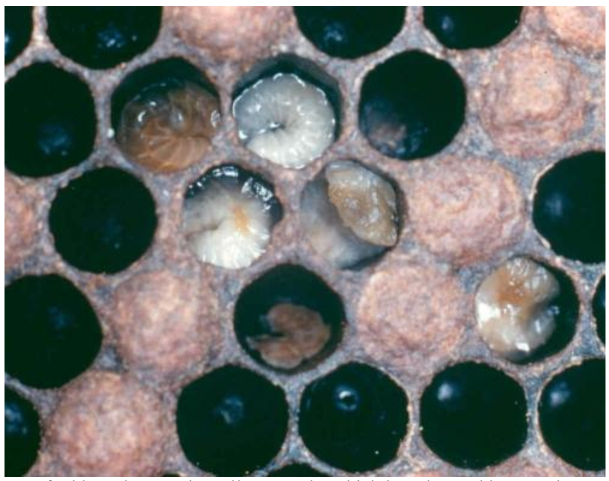
Larva killed by American foul brood. This dead larva contains thousands of spores that will be spread throughout the colony by the workers engaged in nursing activities. Photo by Zach Huang.

If the larval cell of an infected larva is capped prior to death, the capping over the larva becomes moist, dark colored, and sunken.

Brood cells exhibiting the brown, sunken caps characteristic of colony infected with American foul brood. Photo by Zach Huang.

This disease is highly contagious. Destruction of infected colonies by burning is the only proper way to control the spread of this disease. The incidence of this disease is estimated to be 20% in the U.S.

European foul brood is caused by *Melissococcus pluton*. It affects larvae up to 48 hours old, and kills them within several days. Unlike American foul brood, its occurrence is cyclic, with a rapid increase early in the spring. The greatest impact is on small colonies. This condition is less of a concern than American foul brood; in fact many hive owners never realize that their colonies are infected. Colonies moved about for pollination and those with low food reserves are most likely to be impacted. Successful treatment of this condition often occurs as a result of feeding the bees antibiotics (Crane, 1990).



Larvae with European foul brood. Note the yellow streaks which broaden and become brown as larval tissue is destroyed. This continues until the larva dies. Photo by Zach Huang.

Mites

Varroa Mites

Varroa mites are natural parasites of the eastern honeybee, *Apis surana*, from southeast Asia. Unfortunately the honeybees that are found in the U.S. (*Apis mellifera*) have no adaptations that provide them any significant degree of protection from these parasitic mites (Buchmann, 2005). Varroa mites appear as brown specks ranging from 1-2 mm. in diameter. Males are round and approximately 1 mm. in diameter, whereas the oval females approach 2 mm. in diameter.

Various stages of varroa mite development.

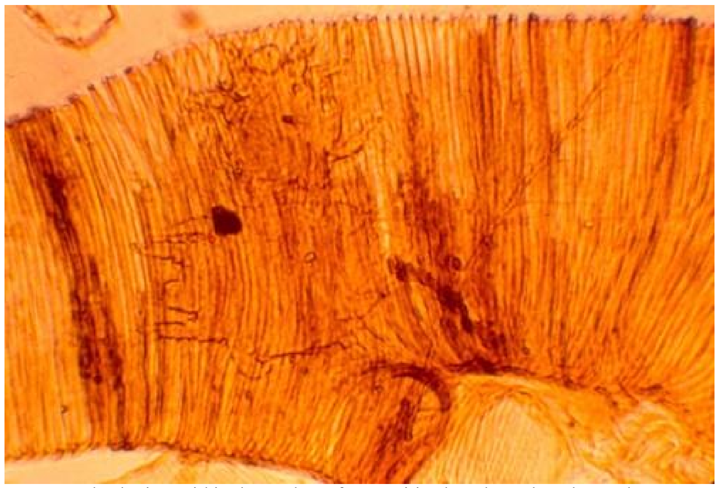
Early in the 1980s varroa mites began to make a serious impact on commercial hives. These mites feed on larvae and pupae, feeding preferentially on drone larvae and pupae.

Larva covered with five varroa mites. Photo by Zach Huang.

In serious cases, the pupae are killed or develop into adults exhibiting reduced size, incomplete wing development, and atrophied legs. One of the major problems in dealing with these organisms is that their activities go largely unnoticed within capped cells, away from the view of even the most vigilant beekeepers. Adults bees become exhausted in their efforts to remove mites. Feeding of the mites causes the adult to lose vital body fluids, while the breaks in the exoskeleton caused by mite feeding lead to increased likelihood of infection by bacteria, viruses, and other pathogenic agents. Often the mites do not appear to make a significant impact on the bee colony until the third year of mite population establishment, when the mites may consume the entire year's larvae and pupae. Acaracides, pesticides developed specifically for mite control, may reduce mite numbers though there is no completely effective control method (Jean-Propst, 1995). Half of the populations of some bees have decreased over the past 10 years as a result of this mite (Buchmann, 2005).

Varroa mites on the thorax of a worker. Note the incomplete wing development in the bottommost adult. This is likely the result of varroa mite tissue damage during the pupal stage. Photo by Zach Huang.

Tracheal Mites
These mites are a natural parasite of the western honeybee. They have been in the U.S. since 1984, and are generally considered a relatively minor pest in many parts of the U.S. (Buchmann, 2005). Only young adult bees are susceptible to this mite. These mites enter the first or second spiracles (air holes) and feed on the wall of the trachea, the tubes used for gas transport. Tracheal mite impact on colonies is often minimal, though infestations in colonies with insufficient food resources further weakens the colony, and may contribute to the eventual death of the these colonies (Crane, 1990).



Two tracheal mites within the trachea of a parasitized worker. Photo by Zach Huang.

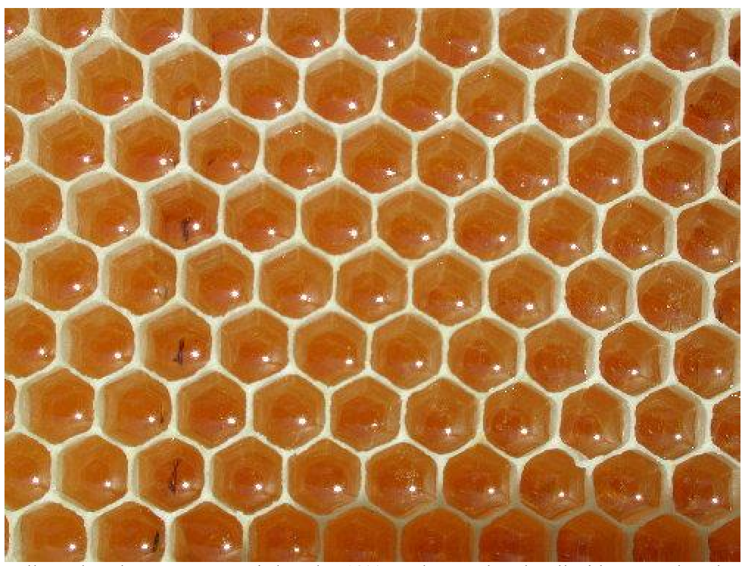
Part 6: Bee Products

The majority of commercial apiary profits come from payment for pollination services. In addition to pollination profits, several bee products are economically significant. The two most common bee products, honey and wax, are produced and used throughout the world.

Honey
Honey is produced from nectar, which is obtained from floral nectaries deep within flowers. Nectar provides a pure carbohydrate source for all stage of the bee lifecycle. Each worker fills her honey sac within her digestive system, increasing her weight by up to one half. Upon arrival at the hive, the worker regurgitates the contents of the honey sac to the younger workers within the hive.

Foraging bee regurgitating stomach contents to younger nurse bees. Photo by Zach Huang.

These younger workers receive the nectar, which is processed by enzymes within their honey sacs, and tipped into storage cells where it then ripens for five days. At this point the substance has becomes honey, and the cell containing it is capped for storage.



Honey in the cells - When the water content is less than18%, workers seal each cell with a cap. Photo by Zach Huang.

Nectar from five million flowers is required to produce a single pint of honey (Tales From the Hive, 2000). During its lifetime, the typical worker makes 1/12 of a teaspoon of honey. A single pound of honey requires two million flower visits. The average commercial beehive produces in excess of 160 pounds of honey per year (Bishop, 2005).

Honey has been used as a sweetener since ancient times. The color and flavor of honey is impacted by the flower source. In general, the darker the honey, the stronger its flavor. For example, orange tree-based honey has a citrus odor and taste (amber color, citrus tang, and orange aroma), while eucalyptus honey is darkly aromatic and somewhat medicinal tasting. Honey made from leatherwood, a component of aftershaves, has an exotic, spicy, aftershave scent.

Buckwheat honey, like other dark honeys, is known for its characteristic strong flavor and high levels of antioxidants. Photo by Zach Huang.

In addition to its value as a sweetener, honey has a number of medicinal and antibacterial properties, and has been used in pain relief and healing of burn victims. The sugars in honey nourish healthy cells and help support the development of new white blood cells. Honey's antioxidants, amino acids and vitamins play a role in reducing inflammation. The antibacterial activity of honey rapidly kills the pathogens that cause typhoid fever, bacterial pneumonia, strep throat and bacterial dysentery. In fact, in 1998 honey was proven to be more effective than silver sulphadiazine, the antibacterial ointment most widely used on burns in hospital situations, in the treatment of burns.

Wax

Beewax has traditionally been used in a number of items including furniture and shoe polish, crayons, candles, lip balms, lipstick, hand creams. In terms of worldwide corporate sales, the five largest users of beewax are 1) cosmetic companies, 2) candle makers, 3) pharmaceutical companies, 4) dentist offices, and 5) chewing gum companies.

Interestingly, bees convert excess food resources within their own bodies to wax instead of fat. Wax glands on the underside of worker abdomens secrete the wax that makes up the honeycomb.

Wax scales secreted by the four pairs of glands on the underside of a worker's abdomen. Photo by Zach Huang.

Production of a single pound of wax requires eight pounds of nectar. This same single pound of wax will be used to make 35,000 brood cells. Though there are likely few people involved in the commercial production of bees for the sole purpose of wax production, the annual wax harvest from commercial hives often provides enough money for beekeepers to refurbish old hives as well as produce some new ones for the next year (Bishop, 2005).

Newly produced wax is a creamy white color. Older wax tends to be caramel colored, while the oldest wax is adark chocolate brown. Photo by Zach Huang.

Part 7: Recommended Bee-Related Resources

Books

Bishop, H. (2005). *Robbing the bees: a biography of honey, the sweet liquid gold that seduced the world*. New York, NY: Free Press.

Crane, Eva. (1990). *Bees and beekeeping: science, practice and world resources*. Ithaca, NY: Comstock Publishing Associates.

Hooper, T. (1976). *Guide to bees and honey*. Emauss, PA: Rodale Press.

Jean-Propst, P. (1994). *Apiculture: know the bee and the apiary*. Andover, Hampshire, U.K.: Oxfod and IBH Publishing Co.

Thompkins, E. & Griffith, R. (1977). *Practical beekeeping*. Charlotte, VT: Garden Way Publishing.

Winston, M. (1992). *Killer bees: the Africanized honey bee in the Americas*. Cambridge, MA: Harvard University Press.

Online Audio Interviews

NPR Diane Rehm Show interview with Holley Bishop, author of *Robbing the bees: a biography of honey, the sweet liquid gold that seduced the world*. March 30, 2005. < http://www.wamu.org/programs/dr/05/03/30.php>

Science Friday interview with Stephen Buchmann, author of *Letters from the hive: an intimate history of bees, honey, and humankind*. June 17, 2005. < http://www.sciencefriday.com/pages/2005/Jun/hour2_061705.html>

Videotapes

Tales From the Hive. Dir. Herbert Habersack. NOVA. 2000. Videocassette.

Web Sites

General

Beetography http://www.beetography.com/ Top quality bee-related digital images of bees. Thanks to Zach Huang for granting us permission to use many of these images on this web site.

Apiservices - Virtual Beekeeping Gallery,
http://www.apiculture.com/_menus_us/index.htm

Bee Information on the World Wide Web, http://www.honeybee.com/index.htm

BeeHoo the beekeeping directory - Beekeeping - beekeeping suppliers, apiculture,
http://www.beehoo.com

Beekeeper's Web Links,
http://ourworld.compuserve.com/homepages/Beekeeping/weblinks.htm

Beemaster's Beekeeping Course Home Page,
http://www.beemaster.com/honeybee/beehome.htm

BEES-ONLINE, http://www.bees-online.com/

The Biology of the Honeybee, *Apis mellifera*,
http://koning.ecsu.ctstateu.edu/plants_human/bees/bees.html

CyberBeeNet (Biology, Research, Beekeeping), http://www.cyberbee.net/

InGenBees, http://www.ingenbees.com/

NCBI Honey Bee Genome Resources,
http://www.ncbi.nlm.nih.gov/projects/genome/guide/bee/

The Pollination Home Page, http://pollinator.com/

Region-based, though lots of general information!

Alaska HoneyBee Home Page, http://balder.prohosting.com/~starrier/

Eastern Apicultural Society of North America, Inc., http://www.easternapiculture.org/

HoozierBuzz.com: The Official Website of the Indiana State Beekeepers Association,
http://www.hoosierbuzz.com/

Illinois State Beekeepers Association, http://www.isba.us/

Indiana Beekeeping, http://indianabeekeeper.goshen.edu/

International Bee Research Association, http://www.ibra.org.uk/shop/erol.html

MAAREC - Mid-Atlantic Apiculture Research and Extension Consortium, http://maarec.cas.psu.edu/

Midnite Bee: Beekeepers Home, http://www.mainebee.com/

Images

MicroAngela's Electron Microscopic Images, http://www.pbrc.hawaii.edu/bemf/microangela/

Scanning Electron Micrographs of Insects, http://www.bath.ac.uk/ceos/Insects4.html

A Scanning Electron Microscope Atlas of the Honey Bee, http://gears.tucson.ars.ag.gov/beebook/bee.html

Miscellaneous

Africanized Honey Bees on the Move: Lesson Plans, http://ag.arizona.edu/pubs/insects/ahb/ahbhome.html

B-EYE: The world through the eyes of a bee, http://cvs.anu.edu.au/andy/beye/beyehome.html