What's the Buzz with honey Bees?

ILLUSTRATING BEEKEEPER MANAGEMENT

by

Skye Young

WHAT'S THE BUZZ WITH HONEY BEES? Illustrating Beekeeper Management

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ILLUSTRATING BEEKEEPER MANAGEMENT

FOR THE HOBBY BEEKEEPER

In order to promote the health and protection

of the Western Honey Bee (Apis mellifera)

by

Skye K Young

  

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Thank you to my mother who has instilled in me a love for research; my father, a vast curiosity; and from both, endless support and encouragement.

This thesis is dedicated to LL Langstroth's hope
"that the many wonders of the economy of the honey-bee will not only excite a wider interest in its culture, but lead those who observe them to adore the wisdom of Him who gave them such admirable instincts."

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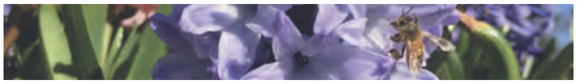
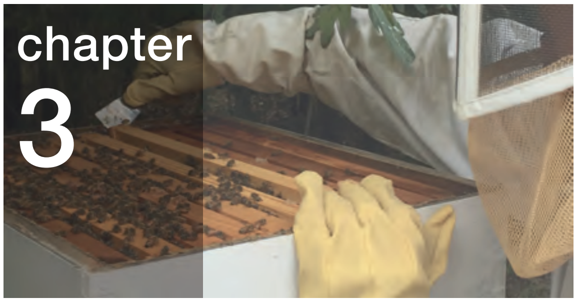
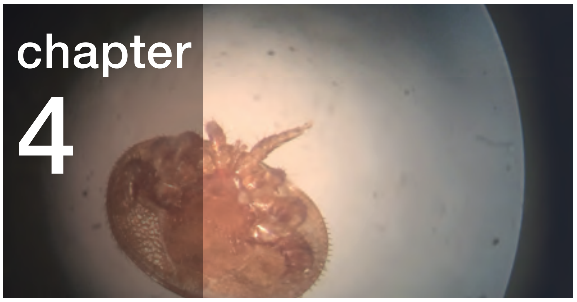
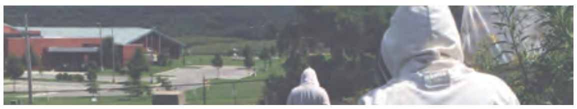
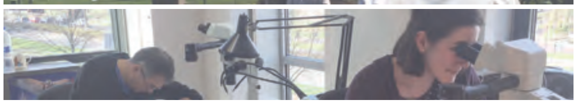
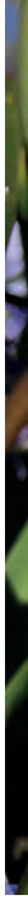












FOREWORD

Somewhere scribbled in the back of an old sketchbook is a Bucket List I wrote when I was 16 years old. Sandwiched between getting a tattoo and riding a double decker bus, I made a goal to one day become a beekeeper. I'm not sure what drew me to it, exactly—I've always loved nature. In fact, 7-year-old Skye wanted to be a nature scientist who travels the world to draw animals (so far, so good). However, I suppose I first loved the products of the hard-working honey bee and only more recently grew to love the little animals themselves. I have made it my objective to keep that perspective while researching, in order to stand in the shoes of my target audience, the Hobby Beekeeper. It is with this dream of beekeeping and a newfound appreciation for the Western Honey Bee, that I look to promote the health and safety of *Apis mellifera* by exploring their brief, magnificent lives and illustrating beekeeper management practices to help continue on their legacy.

This thesis investigates methods of illustrating proper beekeeper management in order to promote the health and protection of the Western honey bee (*Apis mellifera*), as a response to the loss of colonies. Honey bees have played an inextricable part in human societal development and the recent increase in issues leading to colony death has put honey bees, economy and agriculture at risk. Honey bees are primary pollinators of many crops and wildflowers, and pollination is threatened as honey bee colonies decline (Requier, et al., 2015). This thesis illustrates the problems concerning honey bee colony death, but focuses on developing images for hobby beekeepers, as well as nature enthusiasts interested in starting beekeeping or finding other ways of being involved in alleviating the challenging issue of honey bee health. The study thereby magnifies the social value of the project by broadening awareness and offering viable solutions. This means that alongside personal research and the external advisor's provided expertise, this thesis attempts to answer the questions "Which visual approach and strategies can be used to explain the details and importance of honey bee colony death, while compensating for what is lacking in current resources?" and "How can proper beekeeping practices that promote pollinator health and protection best be taught and encouraged through visual education?"

chapter 1

INTRODUCTION

SUMMER IN A BEE SUIT

Hair stuck to my forehead and salty drops slowly slid down into my eyes as I squinted through the bee hat's veil. My gloved hand prodded the mesh in vain as I tried to wipe the sweat from my brow. I was baking in the 100-degree sun, but it was the price I had to pay to protect myself from a potential first-time allergic reaction. Twenty-four years without a bee sting (or any Hymenoptera, for that matter) and I planned to maintain my record! This past summer, August 2016, I had the opportunity to visit multiple hives over the course of my research, all assembled for different purposes—research hives arranged in neatly labeled rows, a small cluster of meadery hives perched in the rolling hills of Virginia, a couple of pollination hives on a small-town American farm, hives in the Netherlands that produce liters upon liters of unique floral honeys, and a backyard hive whose colony was excitedly buzzing from garden to garden. This particular apiary in which I was melting [Fig 1] was Virginia Tech University's Research Apiary (Blacksburg, Virginia, USA), used for experiments, training workshops, raising honey bee awareness and demonstrations, upon the recommendation of my external advisor, Dr. Troy Anderson (entomologist and toxicologist).

This was my first experience entering the world of the bees. Cautiously approaching the hive, I observed the single-minded task fulfillment of its inhabitants as they buzzed in, out and around the supers. Each of them looked like they had somewhere to go, things to do, bees to see. The bee smoker pumped and I expected their hectic activity to slow to a languid pace, but instead the light tune of vibrations swelled to a great chorus of buzzing, and the bees scattered [Fig 3]. The smoke masks the alarm pheromones of the guard bees and encourages eating (Bortolotti, 2014), leaving the bees too busy to be bothered by an animal approximately 80,467 times their size entering their home.

The researchers lifted the lid and pried the frame out of its propolis tight hold. The bees clustered on the comb, continuing their duties of feeding the brood, delivering nectar and honey, and forming cell covers for the developing larvae. However, some of the larvae would never grow beyond their current state, as they rested lifeless at the bottom of their cells. Other honey bees were packing away pollen, regurgitating nectar and covering it with a thin wax to sit and become thick, sweet honey. The primary brood-laying and honey storage normally happen in different boxes of the hive, but this colony was all mixed up and probably queen-less, which I surmised when I noted the large queen cells climbing over the frame edges. Two of the queen cells contained dead larvae, leading us to believe a queen had emerged and tracked down her competition. Drone bees wandered aimlessly around the frames, most likely looking to leech another meal. We put the frames back and walked to the next hive, a much healthier, thriving colony containing an active queen bee with organized brood laying and food storage.

A worker bee flew from the hive and I followed her to a stalk of knapweed. She tiptoed over the bright purple corolla and nestled her face between the many little flowers that make up the inflorescence that we see as a single flower head. With each visit, she collected the nectar with her long proboscis, carrying her sweet discoveries in the honey stomach until she flew back to the hive.

This exploration into the world of honey bees was the first time I had been able to experience the eusocial insects within their own home and truly appreciate their incredible communication skills and hard work.

Fig 1

BEEKEEPING HISTORY

Personally motivated by my curiosity of the bees since my summer in a bee suit, I've spent my time researching, hoping to answer my numerous questions, starting with early history and working up to honey bees today. Why do we care about bees so much that we've "domesticated" them? What's happening to them and how does it concern us? What's all in a day's work for the honey bee? During this journey, I've attempted to evaluate their importance to humans, their synergistic relationship to their environment, and discover how easy it is for a novice to become a passionate, fully-involved beekeeper.

Honey bees have been appreciated for their honey production worldwide since long before the Ancient Egyptians. Yet, they are not only important for their honey production, but also for crop and flora pollination. As humans settled into farming lifestyles, a dependency on honey bees for pollination developed (Jones & Sweeney-Lynch, 2011). Honey bees are importnat pollinators for many crops such as almonds, squash, watermelons, lemons and limes. In fact, the value of insect pollination in Canada and the US equals $20.1 billion, largely provided by honey bees who remain "the most important pollinator for most crop monocultures worldwide" (vanEngelsdorp & Meixner, 2010). Honey bees have followed the migration of humans and are now prolific on every continent, except Antarctica, where there are no bees (vanEngelsdorp & Meixner, 2010). The Western honey bee (*A. mellifera*), however, was first introduced to North America from England during the colonization of the "New World" in 1622 (Webber, 2012).

It was not until 1851 that Philadelphia clergyman L.L. Langstroth revolutionized domesticated beekeeping with his invention of the movable frame and his lifelong research devoted to the apicultural arts. Despite his nearly two-century old invention, the movable frame hive is still the most efficient for regular evaluation of the bee colony, manual structural separation of the brood and honey, and overall responsible beekeeping [Fig 2]. He also discovered what is commonly known as "bee space," which allows easy removal of the hive cover due to the honey bees' unwavering instinct to fill in spaces smaller than 6.4 mm with propolis and those with more than 9.5 mm, with comb (Ambrose, et al., 2010). His comprehensive book on all-things-honey-bee, The Hive and the Honey Bee, continues to be the most valuable resource for beekeepers. This book includes illustrations by the Smithsonian's National Museum of Natural History's finest entomological researcher and illustrator, Robert E. Snodgrass, and in its newer editions, the useful addition of electron microscopy images. While most of the surveyed information included in the book is only referenced up until the 1980s, more recent research can be found in published and peer-reviewed journals such as the *Journal of Invertebrate Pathology* and *Agriculture, Ecosystems and Environment*. Since the 1980s, the honey bee has been plagued by some of its most formidable foes, so those challenges are not included in Langstroth's book.

Fig 2: From the Library of Congress, Utah beekeeper Donald Gill attending his hive, 1940

BEE DECLINE

Honey bees have been dying in alarming percentages since the hard onset of Colony Collapse Disorder (CCD) in 2006 and before that, the introduction of the *Varroa* mite (*Varroa destructor*) in the late 1980s, which according to

Rosenkranz et al., is the "most detrimental honey bee parasite in the world today." As of 2014, beekeepers in the United States have continued to lose a staggering 32.7% of their colonies each winter (Winston, 2014). Honey bees are one of the few species of bee that is meant to survive the winter, but this is becoming increasingly unusual. Colony deaths are due to a dangerous concoction of problems, including but not limited to pests, parasites, fungi, pesticides, genetics, climate change, and nutrition. Hobby beekeepers are aware of some of these problems, whether from their own experience in keeping bees or from the repeated warnings from their predecessors, mentors or local beekeepers' organization. Oftentimes, however, the whole picture is not given, but just a piece or two of this fatal puzzle.

To truly understand how to help the honey bees, beekeepers must have a clear idea about how these problems interact with each other and exponentially increase the risk of death in honey bees. These problems, or stressors, include recognizing pests and disease in the hive, lack of nutritional variety, atypical brood laying and behavior, queen health and more. With the visuals I provide, my goal is to encourage beekeepers to engage bees on a deeper level so the keepers will be open to and aware of changes in the bees' habits and life quality. I realize that beekeepers may not change their ways, despite learning more on the topic. Beekeepers are often set in their thinking when determining the root of all honey bee problems.

Regardless, the willingness to learn more is important because beekeeping has evolved since its ancient days, where bees could simply occupy a woven skep or hollow log and occasionally be intruded upon by humans seeking honey. Now, there are multiple new problems, due to pest introductions, pandemic spread of bee disease and a high demand for pollination and honey. Additionally, it is very important to notify beekeepers about how different interacting stressors can be lethal for bees. For example, *Varroa* mites can weaken the immune system and transmit viruses, leaving

Fig 3: Smoking the hive before removing any frames at Virginia Tech University's Research Apiary. Blacksburg, Virginia

honey bees more vulnerable to other diseases, like Deformed Wing Virus (DWV). DWV makes individuals less productive and more likely to die sooner (vanEngelsdorp & Meixner, 2010). Worker bees infected with tracheal mites will have a harder time flying in cool weather, which makes long foraging trips deadly. A lack of nutritious foraging material causes bees to increase their foraging flights to get the food they need to feed their brood, and decreased foraging flights, along with disease, results in added stress to bee colonies (Naug, 2009). Unhealthy brood are even more susceptible to death from parasites and disease. And so it continues, the bees weaken, their production weakens, pollination diminishes and the colony falls apart. These are not all of the factors affecting bee colony health, but beekeepers must know that it is not just about removing the pesky hive beetles from their hive or planting a few nice flowers. Evaluating these

Fig 4

problems takes an attention to detail, focus and intimacy with the hive. In his riveting vignette about visiting an apiary, Dr. Mark L. Winston calls it "a full-body experience being among the bees," further listing the sounds, textures and smells, the light touches of the bees and the complexity of their interactions (Winston, 2014). Hobby beekeepers are in a lucky position, in that they do not rely on their bees for their primary income, but instead keep bees out of interest and possibly supplemental income. This enables them to have a certain devotion and responsibility to care for their hives and to delve into their senses with every visit.

WHAT'S THERE AND WHAT'S MISSING

As a beekeeper wannabe, I have scoured the internet for easily available sources on this information. After speaking with the beekeepers I met over the summer, I narrowed my search according to the current concerns in apiculture to learn more about stressors (see more in Chapter 4). I used JSTOR and Science Direct for access to peer-reviewed journals and articles, as well as a small collection of books and guides for beekeepers that I bought after checking credibility and reviews. Additionally, I located my nearest beekeepers' organizations depending on where I am living at the time, such as the Richmond Metro Beekeepers Association, the Loudoun Beekeepers' Association and, now in the Netherlands, the Maastricht Bee Collective.

Local beekeeper associations have material, or links to material, about beekeeping management, as well as workshops and lectures to help educate beekeepers about creating and maintaining a working beehive. However, there is little cohesive and clear literature detailing management practices and how the problems that affect a single beehive work together. It is a world of endless forum threads and poorly drawn pictures.

It is also necessary to describe a variety of treatment possibilities, with consideration of individual hive factors, so that beekeepers can choose the treatment that fits best for their bees. There is plenty of research about the interaction between diseases, pests, pesticides, and other problems that affect the bees; however, this information is not user friendly for the aspiring beekeeper. The presentation of scientific tables and graphs does not explain the action needed to manage the factors that affect bee colony health. The data must be clearly articulated to beekeepers so they can find the best solutions for the health and safety of their colonies in their region. Moreover, ultimate awareness and senses that one experiences when entering the hive is something that I think should be properly communicated with illustrations provided to beekeepers.

The Beekeeper's Bible by Richard A. Jones is another publication that provides an "ultimate guide to the practical essentials of beekeeping" and is a "beautiful almanac to be read from cover to cover". It is directed toward the hobby beekeeper and nature enthusiast. The author is certainly qualified as a "nationally acclaimed entomologist" in the UK and has previously served as president of the British Entomological and Natural History Society. The book itself is comprehensive and explains everything from the history of beekeeping to practical uses of bee products, with recipes and instructions in the back. *The Beekeeper's Bible* is an excellent resource and uses both photography and illustrations to explain the bee, from A to Z. The amount of information provided in the book I found to be a challenge. It is a beautiful book, but it is not something a beekeeper can readily take out to their apiary to compare pollen colors and brood patterns in the hives. Neither is it a resource that would be taken to the local nursery to pick out the right flowers to plant for the bees, to test the comb for disease, or to observe the health of their bee colonies. What is needed is something quick, straightforward and essential to evaluate colony health.

The Beekeeper's Problem Solver by entomologist and apiculturist Dr. James E. Tew is the closest example to an informative and practical visual guide for managing bee colony problems experienced by beekeepers. This book was printed in 2015 in the UK and US. It lists 100 common problems beekeepers can encounter in their apicultural journey. It is very clear in text, offering a viable cause and solution for each problem. However, most of the accompanying images do not aid in describing, visualizing or solving the problems. I do think illustrations are necessary, and I aim to rectify this lack and create my own resources to fill this need.

WHAT I LOOK FOR IN AN ILLUSTRATION

During this process, I was not only concerned with analyzing the use of images, but discovering the information that accompanied these images. I evaluated the visual articulation, legible labeling, accurate representation of the subject matter, helpful choices made in the translation from reality to illustration, scale, consideration of the intended audience, reference points to distinguish perspective, and the uses of color, pattern and texture.

PURPOSE & INTENT OF THE RESEARCH

The purpose of this research is to discover the best way to visualize the honey bee problem for hobby beekeepers, to raise awareness about the honey bees and their specific problems. This research explores which visual strategies and aesthetics can be used to explain the causes and importance of hive death, while compensating for what is lacking in current resources. As a scientific illustrator, my goal is to provide visual and textual knowledge about what beekeepers and enthusiasts can be doing to help alleviate the causes of honey bee death through a comprehensive, accessible honey bee and colony health assessment guide that will provide relevant background information and illustrations to identify problems, as well as preventive measures to treat unhealthy bee colonies. In addition, this thesis investigates how proper beekeeping practices that promote pollinator health and protection can best be taught and encouraged through visual education.

Illustrations have proven to be vital additions to aid learning and understanding. Research studies provide information for how illustrations can improve learning from text. For example, Levin and Mayer (1993) suggest that visuals can make text more concentrated, concise, concrete, coherent, comprehensible, correspondent and codable. However, to do this, the illustrations must add another dimension to the information and be intentional with the audience, including the age, reading ability and "visual literacy" (Carney, 2002). In the case of my research, I am reaching out to a broad, yet interested, demographic of current or potential hobby beekeepers. In multiple studies, it is noted that "…[learners] with low prior knowledge profited most from comprehensive, informative visual illustrations (Ollerenshaw, 1997)." Additionally, it is crucial that the visuals be essential in the information that they provide. Abstract linear and detailed shaded drawings are both more effective than pure text, oral presentation or photographs for total conceptual understanding (Dwyer Jr., Adapting Visual Illustrations for Effective Learning, 1967). Dwyer's research shows that, when time is short, a reduction in detail can enhance learning, without distracting the viewer. However, there are "significant differences in the effectiveness of different types of instruction for different educational objectives" (Dwyer Jr., Exploratory Studies in the Effectiveness of Visual Illustrations, 1970). In this research, I attempted to create understandable illustrations of beekeeper management for hobby beekeepers. This will provide the resources hobby beekeepers are missing: straightforward guides that teach them how to engage all of their senses in caring for their hives with updated information and resources that are clearly labeled with comprehensible illustrations.

chapter 2

THE BEE

Fig 5

"Save the Bees" was my main objective at the beginning of this undertaking. However, I was soon posed with the question…who are the bees? Contrary to popular belief, not every little, striped, buzzing creature flying around can be called a bee. In fact, there are many bee mimics and look-alikes, with only a few morphological and behavioral differences. Soon, I was in a spiral of discovery as the world of bees unraveled before my eyes. There is confusion in representation of bee varieties, especially between honey and bumble bees, as they are often collectively depicted as a simplified, singular yellow and black striped body with a head and wings. This simplified bee form is commonly depicted in children's literature and is associated with producing honey, but I quickly learned that only members of the *Apis* genus are considered true honey bees, which does not include bumble bees. In fact, bumble bees do not live in large traditional "beehive" shaped hives hanging from trees (which seem to be a fictitious combination of wild honey bee comb and dangerous paper wasp nests), but rather, they nest into the ground. Not all bees live in colonies, but instead choose a solitary life in small holes in logs or other left behind items, inspiring the "solitary bee hotels" now popping up in university gardens and farms. Only honey bees, of which there are seven recognized species (and many more races), have been "domesticated." These eusocial animals are used as model organisms for social evolution, learning, memory, and pesticide exposure studies (Predel & Neupert, 2007). During my research studies, I found a focus on the Western honey bee (*Apis mellifera*: "*Apis*" bee; "*mellifera*" honey-bearing) due to its prolific inhabitance and our heavy dependence on them for pollination and honey production in North America. Soon, I had an overwhelming and extensive list of terminology to define. However, it would not be long before words like *apiculture, propolis* and *hemolymph* would become part of my regular vocabee-lary.

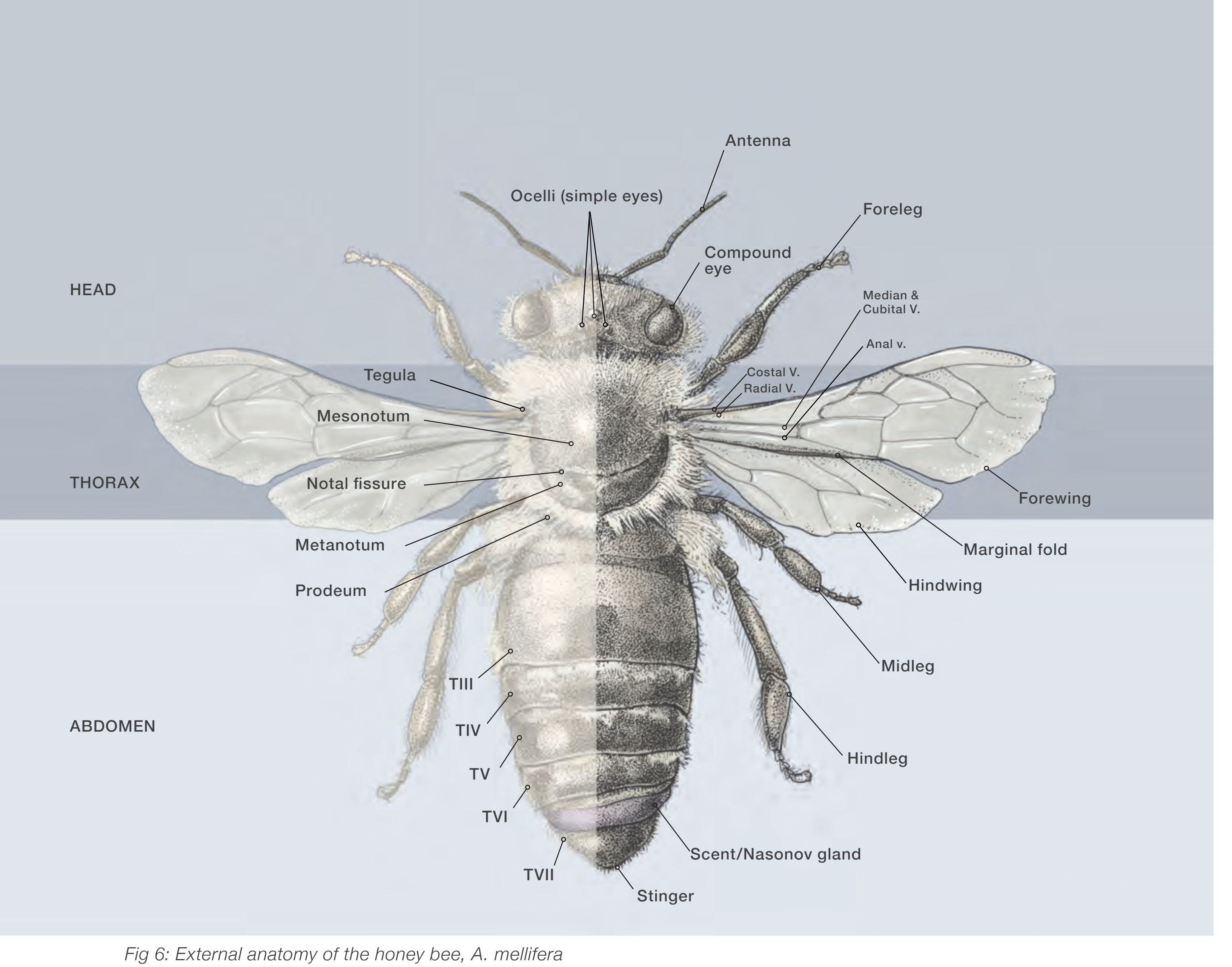


Fig 6: External anatomy of the honey bee, A. mellifera

HONEY BEE ANATOMY

I narrowed my beginner's search to anatomy, physiology, physical development and the honey bee eusocial caste system, including their purposes in the hive and how they were constructed for the services they provide. R. E. Snodgrass was an amazing investigator of insect morphology and, thus, it is no surprise to find his illustrations to be the most detailed, accurate and fully explored anatomical illustrations of the honey bee. However, I found that reading the illustration labels to be laborious, with leading lines to confusing abbreviations that required searching for a definition in a dense paragraph below each figure. Color is a useful tool for illustrators, as it aids in visually distinguishing between anatomical structures. Without the use of a color or pattern in Snodgrass' illustrations, it was especially difficult to define larger structures when only minor structures were labeled, such as in describing the structures of the mouth. A study conducted on the effectiveness of visual illustration concluded that "the effectiveness of the color [illustration] may be explained by the fact that the realistic detail in the visuals was accentuated by color [and] …students were better able to make the appropriate discriminations and to obtain the necessary information required to achieve…" (Dwyer 1970). I found other resources that lacked accuracy as well as definition and detail, whereas others were overwhelming with color and information. A common problem was the legibility of the labels, with many illustrations encumbered by crisscrossed, disappearing or undefined indication lines, multilayered labeling systems or confusing color-coding. There was a lack of consideration for the physiological purposes of the anatomy and attention to the honey bees' unique structures, such as the pollen baskets, honey stomach and wax glands. These structures were mentioned on occasion in beekeeping guides, but without any visual reference.

ANATOMY DISCUSSION

I planned to solve these discrepancies by utilizing modern technology to clarify information, labeling and fusing it with the traditional practice of rapidograph stippling illustrations. The external anatomy of the honey bee was drawn through my personal investigation of acquired specimens. These were first drawn under the microscope using a *camera lucida* [Fig 7]. A *camera lucida* is an attachment to a microscope that allows the viewer to see both the magnified subject and the artist's paper/hand via lights and mirrors. It is an extremely useful tool to secure the accuracy of the measurements and proportions of the specimen, but it is actually quite difficult to get used to, as you have to train your eyes to work together to see two different fields of vision simultaneously.

Fig 7: Camera lucida at Hogeschool Zuyd

As part of my anatomy understanding and exploration, I used Robert E. Snodgrass's illustrations from his publication *The Anatomy of the Honey Bee*. I drew the honey bee from both a dorsal [Fig 8] and lateral view. Additionally, I deconstructed the honey bee into its major forms and made a registration of each piece. This included both the forewings and hindwings [Fig 21], the head, thorax and abdomen, and one of each pair of the six whole legs. Then, I returned to these drawings and labeled them with the proper anatomy, sometimes using transparent paper to arrange the labels and make small sketches to further elaborate the drawing. During my drawing process, I needed to make the choice between drawing a single specimen and drawing with the epistemic virtue of truth to nature. Truth to nature would result in the ideal honey bee, whereas objectively the drawing would include

Fig 8

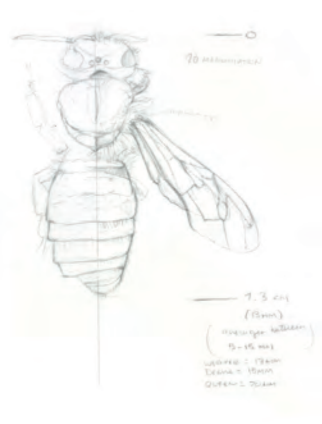
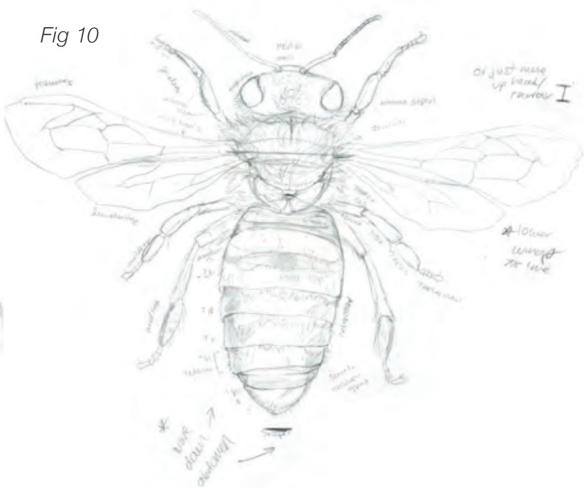


Fig 9

Fig 10



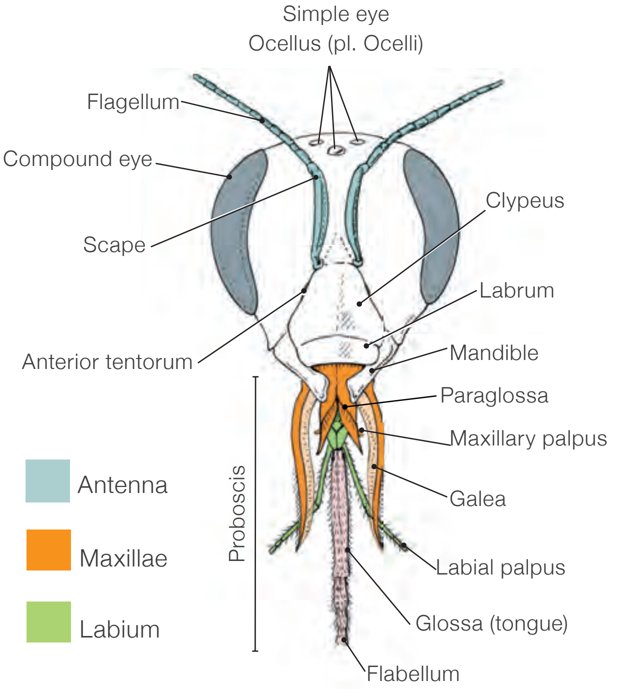


Fig 11 (above): Facial anatomy of the honey bee

Fig 12 (left): Inking the external anatomy

artifacts and natural variants due to the position of its death, holes in the wings, missing limbs etc. I first drew a single specimen for my registration [Fig 3] to get a feel for the general form and anat8my. However, this specimen had curled somewhat at death and its wings and legs were in disarray. Using two more specimens [Fig 9] and objective reference photos, I averaged the body shape and size to create a relatively ideal "true to nature" honey bee for my final external anatomy illustration [Fig 10]. It was important for me to keep the honey bee looking organic and not a symmetrical machine-made bee. I chose to use the rapidograph pens to create a rendered line and stipple illustration with enough rendering to infer hair, form and color difference, but without distracting from the anatomical structure. I scanned this illustration and added anatomical labels. One challenge I faced was in labeling the larger regions of the body—the head, thorax and abdomen. I decided to utilize background colors to identify these, instead of coloring the actual illustration, so I had the option to use color in different anatomical labeling. With the background colors in place, I was also able to depict the transparency of the wings by reducing the opacity in those areas.

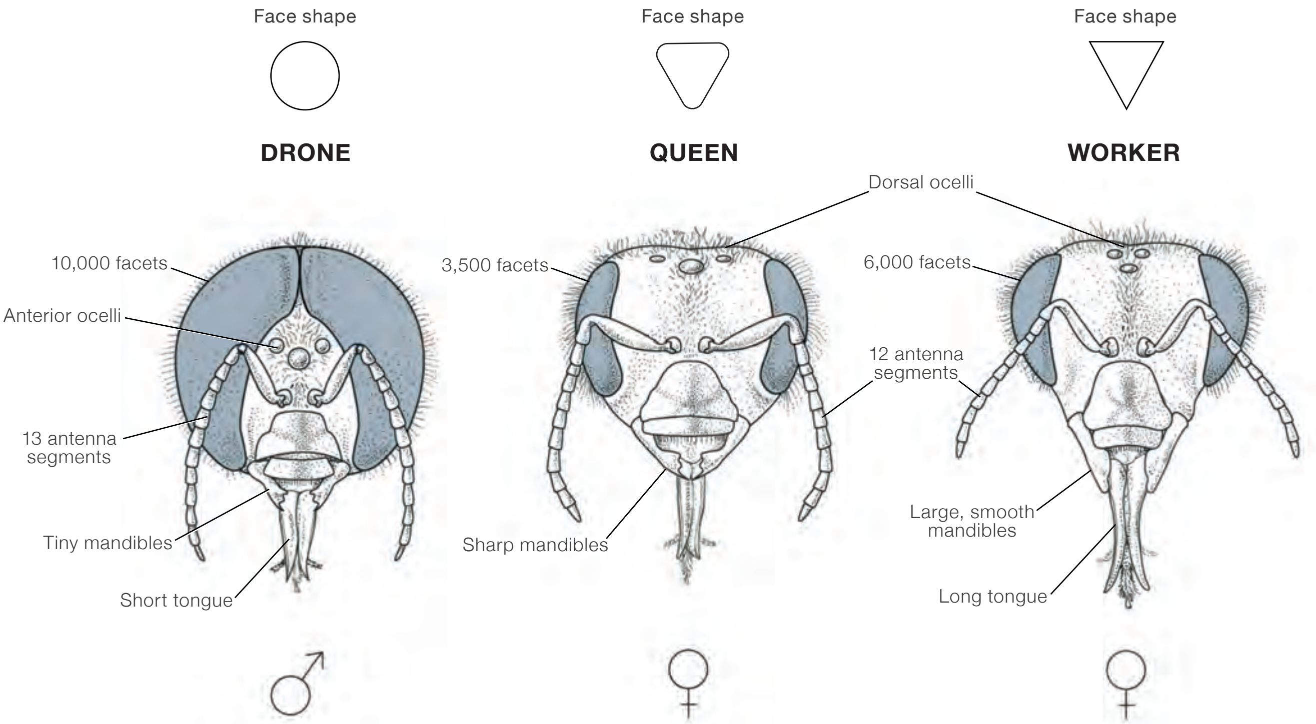
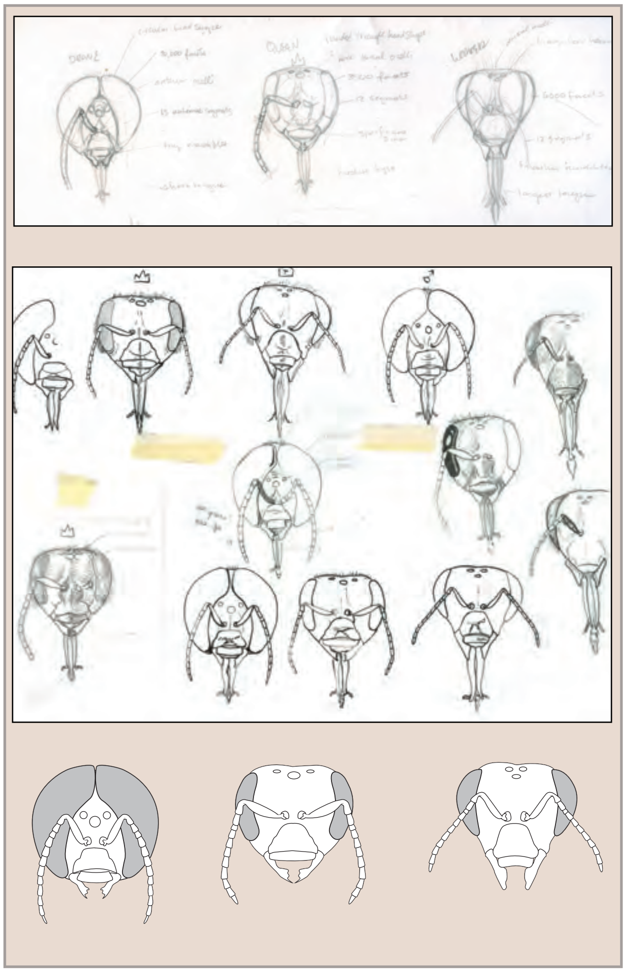


Fig 13 (above): Comparative head anatomy of the drone, queen and worker honey bees

Fig 14 (right): Process work for comparative head anatomy



HONEY BEE CASTE

Special anatomical characteristics are also important to define for the comparison and contrast of different castes, or members, of the bee colony. As a first-time bee visitor, I had a difficult time understanding what to look for when spotting the differences between worker bees, drones and the queen, including where they might be located in the hive. The color and pattern differences on the abdomen are often overlooked with each caste member. Even after seeing them in person and continuing my research, there was a lot to learn about how their form follows function. This includes the different reproductive structures and physical shape/form of the eyes, antennae, abdomen, legs and stingers.

An example of this type of illustration can be found in *The Beekeeper's Handbook*, which uses electron microscopy to show the viewer a worker bee's physical components that make it such a good pollinator. However, these images are not easily readable, as they lack resemblance of visual perspective and anatomical positioning.

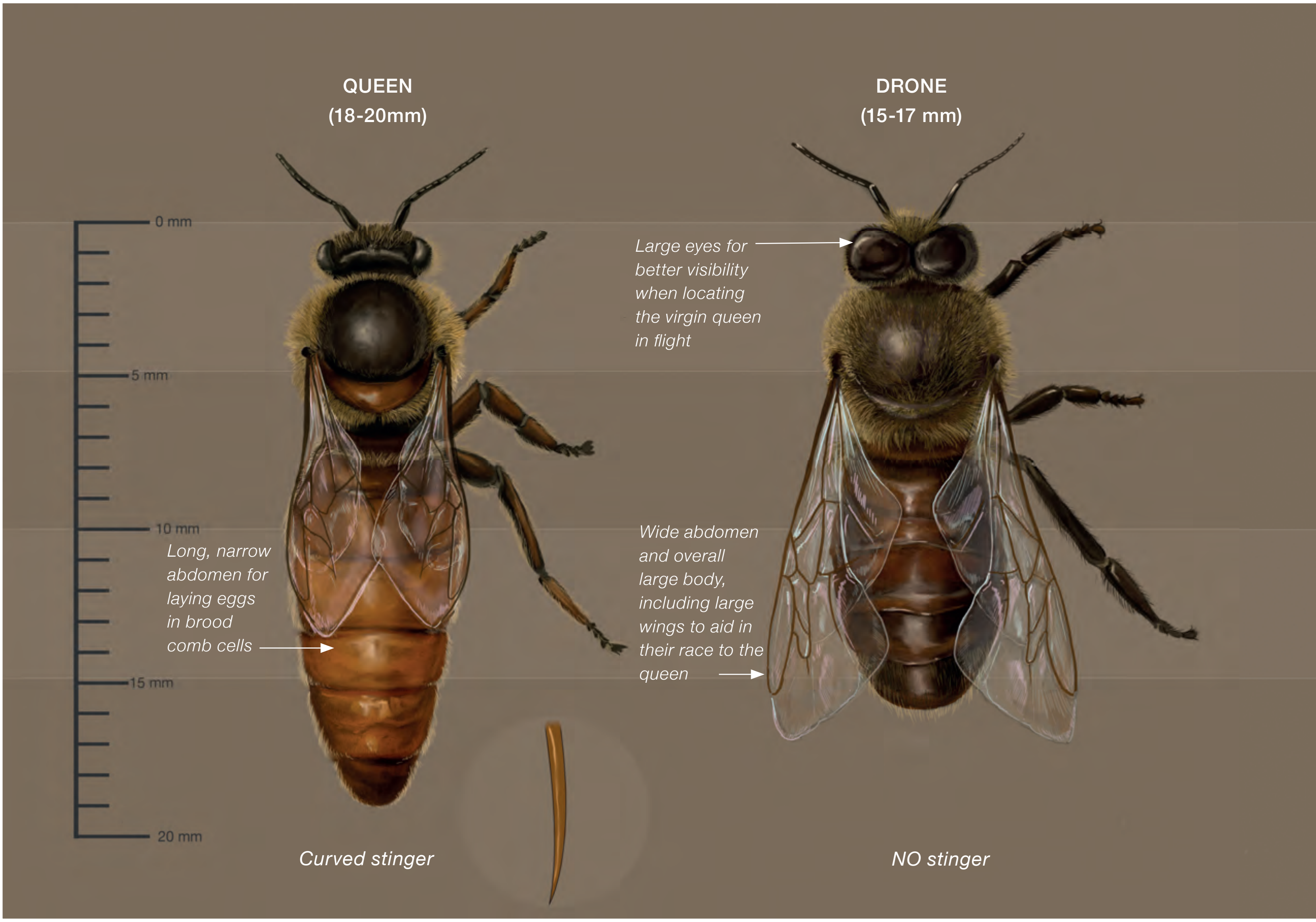
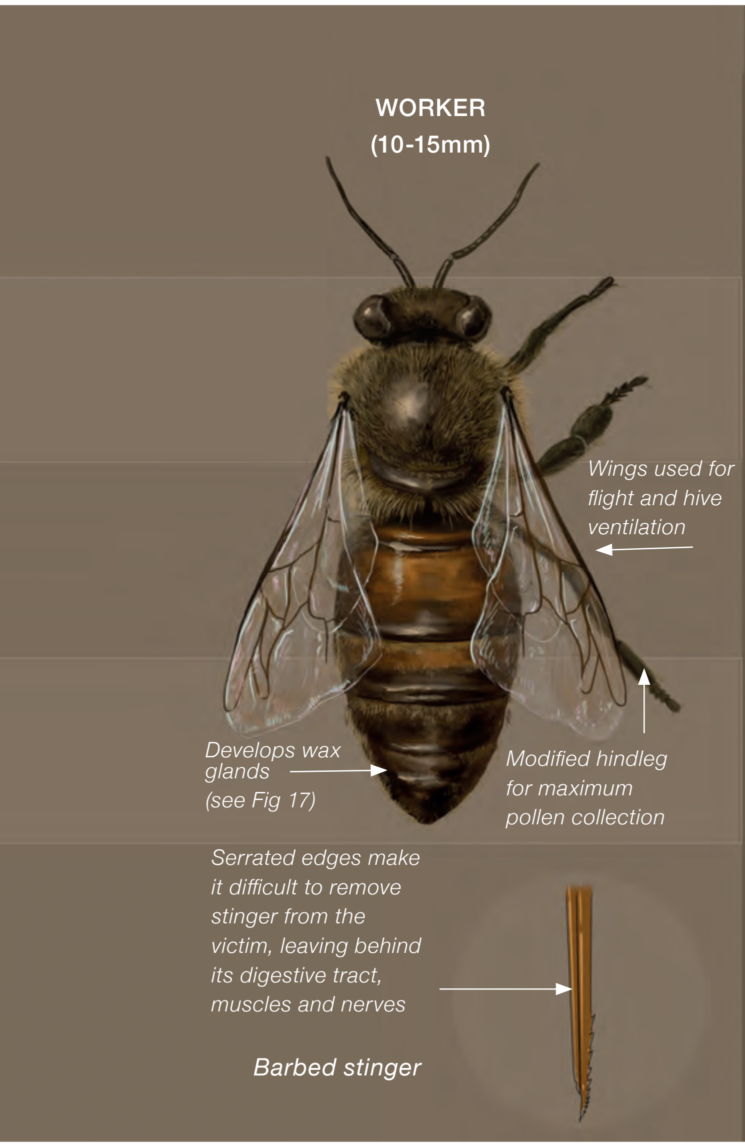
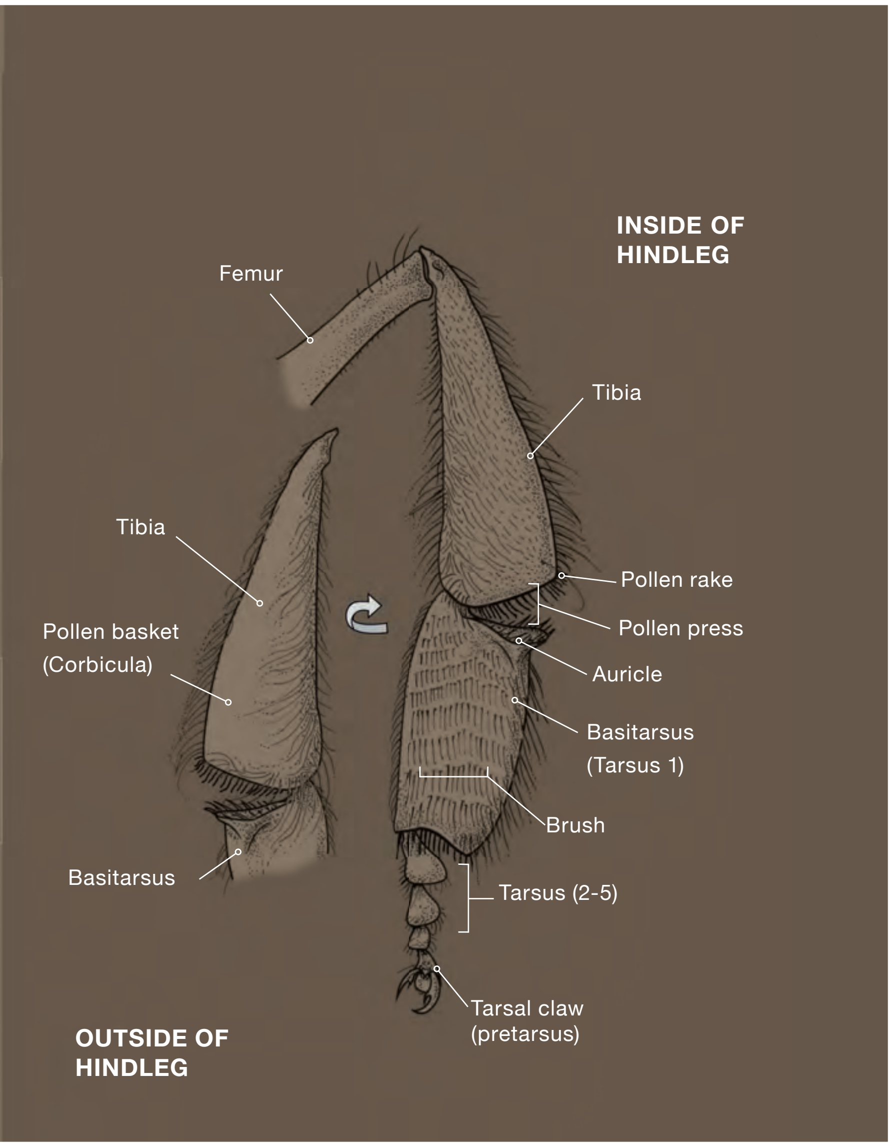


Fig 15: Comparing the members of the honey bee caste and their special features
FIG 16: The inside and outside of the hindleg of the honey bee worker

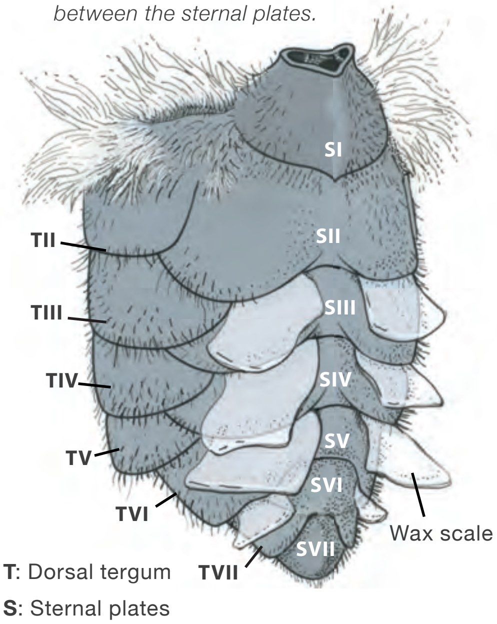
CASTE DISCUSSION

I first made a list of the defining differences for each caste member. The special characteristics of the honey bees included the head structure, pollen basket, wax glands of the worker bee and the stinger varieties. Initially, I sketched these when making registrations with my worker bee exploration [Fig 14, 18, 22]. For the other differences, I used informative macrophotography found online, as well as Snodgrass' in depth anatomical illustrations and a few of my own photos. As I started to do more research for the wax scales, however, I realized that I had misunderstood the anatomy I had previously drawn in my registration [Fig 18], so I returned to a new specimen to redraw the correct tergum segments of the abdomen [Fig 19]. To develop these images, I chose to make clean lines digitally in Adobe Illustrator (a vector graphics program), but also return to traditional elaboration. I accomplished this by using my registrations as a base for the Adobe Illustrator line-work [Heads: Fig 14, Wax scales: Fig 20]. I then experimented with different stippling and ink rendering techniques [Fig 12 & 14] before printing the line drawings on good inking paper and, using rapidograph pens, stippling the anatomical pieces. I chose these media according to the amount of information I considered necessary to convey. For example, the hairs on the face are not as important in defining the differences between the caste members, whereas the hairs and structures on the hind legs are vitally important in their functional variances. The head illustrations are primarily intended to indicate structures, but to aid in understanding the form, they include some stippling.





The ventral abdomen of the worker honey bee, showing wax scales emerging from in between the sternal plates.



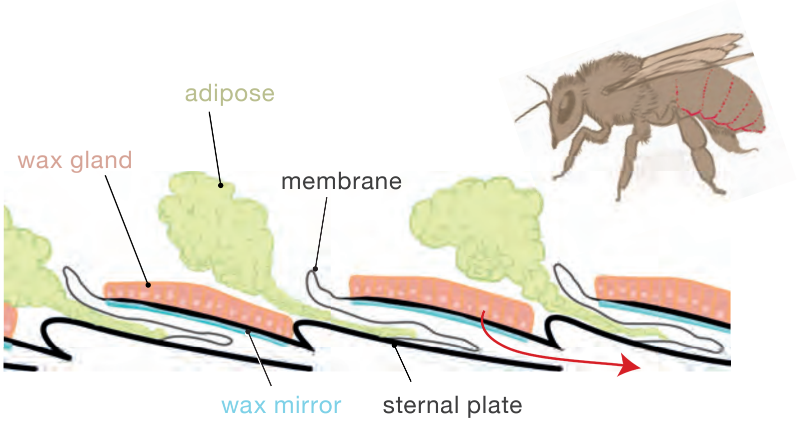


Fig 17: The wax gland is a one cell layer gland that secretes liquid wax through the wax mirror. It hardens and builds up until it is forced through the spaces between the sternal plates. These are called wax scales and come in different shapes and sizes, especially those between the 5th and 6th sternal plates (SV & SVI). A squeeze of the abdomen pushes the scales further out, where they are grabbed by the worker's hind legs and passed forward to be molded and placed with the mandibles. The wax gland is most active between 12 and 18 days old, and then diminishes again by 21 days old. (Collision, 2015)

Fig 18

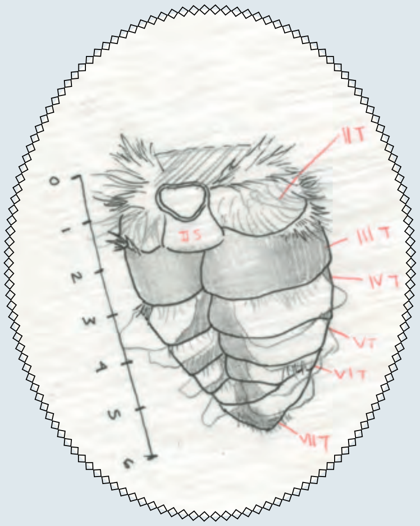
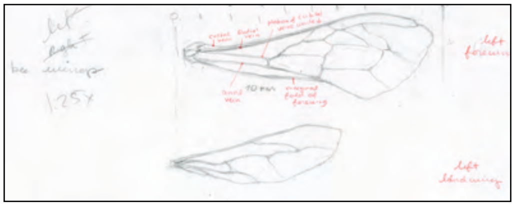


Fig 19

Fig 20



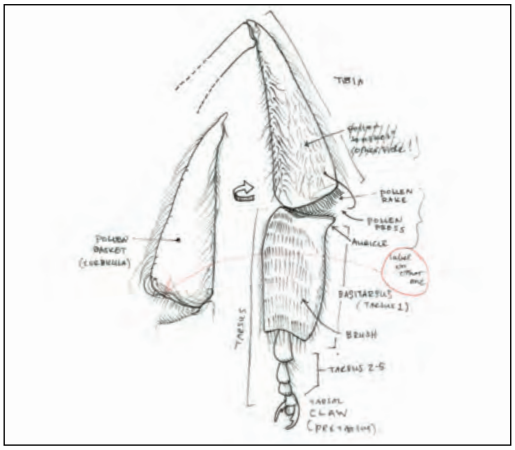


Fig 21 (top): Fore/hindwings; Fig 22 (bottom): Hind leg registration

I have subsequently included an overview illustration of the honey bee caste members that is further rendered to identify each individual using color, texture and form. It is important to note that precise colors and patterns vary between the *A. mellifera* races, as well as each individual bee. My goal was to provide an illustration that not only differentiated between these caste members at a cursory look but also clarified the important functional, external anatomical differences between the drone, worker and queen bees. Furthermore, I found it important to explain why they are different, and why it is important for the viewer to understand these differences in each of the three caste members. When I first approached this illustration, I found it first necessary to scale the bees in relation to each other and with reference to their overall dimensions. In my initial drawing, I arranged the bees side by side to compare their differing sizes, using a temporary guideline to equalize the beginning measuring points at their "foreheads" and adding a scale on the left to define their length. When labeling, I clarified average length ranges for each bee. To draw the bees, I used a collection of my own reference photos from my trip to the Virginia Tech Research Apiary, as well as my worker bee specimens and accompanying registrations.

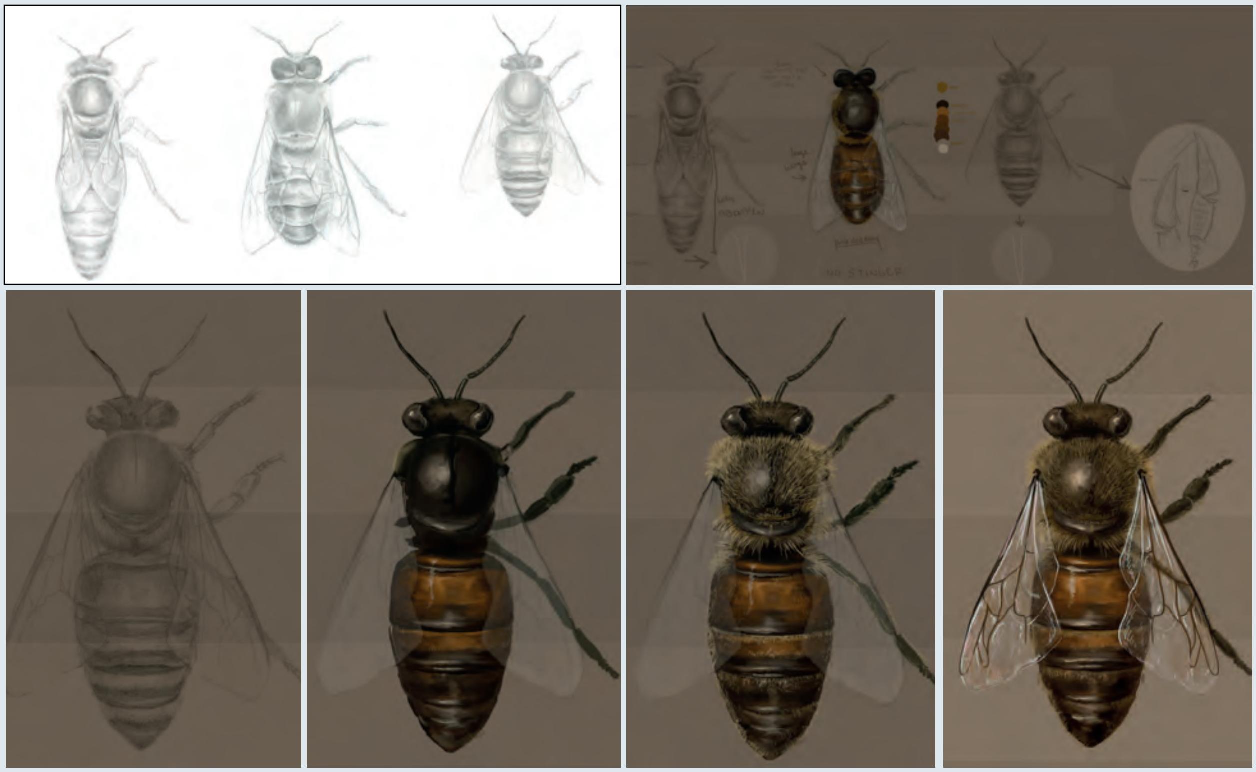


Fig 23: Process work in creating the honey bee caste illustration (see Fig 15)

I first rendered these drawings in graphite pencil to describe the shape and form of the bees in a natural, organic, hand-drawn manner [Fig 23]. These images were then scanned, opened in Adobe Photoshop and "multiplied" (a tool that makes white transparent) over a midtone brown background. This gave the illustration a colorful starting point to work up the form with darker values/bright highlights and made the more vibrant oranges and yellows pop. I chose to digitally paint in Adobe Photoshop over Illustrator to further elaborate the colors and textures so that I could retain the natural representation, especially the unique reflective, matte surface of the bee and the deep polished wood-like colors of the abdomen. I chose this digital method because of the ease with which I could keep a consistent palette, add light colors over dark (referring to the light blond hairs over the dark exoskeleton), as well as include absolute white for the stark reflections on the wings and smooth tergum. The primary brush I used was the standard Adobe Photoshop oil pastel brush, in combination with the color mixing brush, to keep a painterly, uninhibited touch to the rendering.

BEE DEVELOPMENT

Illustrations of honey bee life stages are numerous, and almost all have the same general lateral perspective. This is certainly important in order to show the physical growth of the developing honey bee. However, I believe that it needs to be dually viewed from the perspective of the beekeeper, in order to understand what the cell will look like in instances where the brood may not be capped due to in-hive pests or problems ("bald brood" see Fig 27). Some visualizations also presented information in conflicting order, showing the development from right to left, instead of a more natural Western left to right. Another common issue I found with the research was that many times photographs were present in place of illustrations, but they were grayscale or black and white, and had poor resolution. As a result, these images were next to useless in understanding the subject matter. In my background research for this topic, I had difficulty finding how the cocoon plays a role in the development of the honey bee and what that

Fig 24: Life stages of the honey bee; superior and lateral views

looks like at the pre-pupal stage, leading me to more extensive research. I soon discovered that while the molting process was very important, the “skins” were thin and transparent, and the process is quite quick and impossible to view by a beekeeper—a sign that while important to mention, it is not necessary to illustrate. What can be seen is the change in coloring of the brood during these stages, which demonstrates the importance of using color illustrations to identify the life stages of the honey bee.

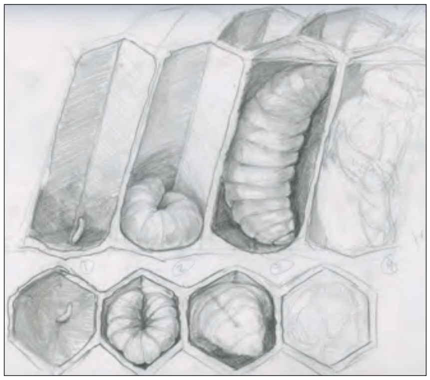
DEVELOPMENT DISCUSSION

With my illustration, I intended to naturally show each major developmental stage of the honey bee and without excess information, while making it easily readable and directly translatable to a real life situation, including the beekeeper’s perspective. In addition, within this sensory-indulgent thesis, I find it important for the illustrations I create to represent the true colors, textures, forms and transparencies of the developing brood, not only for the sake of naturalism, but also to avoid confusion with what normal brood look like in comparison to diseased brood infected with pathogens [Fig 27, Fig 48-51].

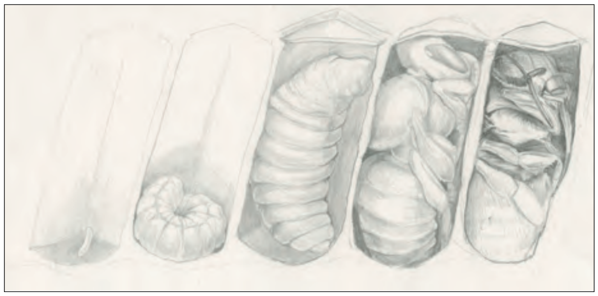
My drawings were created from a large collection of photo resources, as it was winter and I had limited avilability to fresh specimens. I approached the rendering of this image in the same way as the caste member illustrations—drawing the voluminous, fully textured brood in graphite first, followed by scanning the drawing and continuing to render it digitally in Adobe Photoshop to achieve the amount of translucency and fluff needed to describe the subject matter.

I chose to represent the bee in the stages of egg, larva, standing larva, translucent prepupa and mature bee, while using the text and a simple graph to describe the general timeline of the bee's development. I chose to show this development from both the lateral and superior view. From the first sketch [Fig 25A], I realized a lack of crucial detail I had learned from my visit to the apiary: the cells are set at a 14 degree angle, from their base to the opening. This was overlooked, most likely because brood comb in photo and illustrative references are commonly depicted at 90 degree angles. Before elaborating the illustration any more, I restarted [Fig 25 B & C]. I scanned it in and did a quick digital color sketch [Fig 25D]. Then, I transferred it to Schoellers drawing paper and fully rendered it [Fig 25E].

After finishing the drawing, I decided that, for clarity's sake, there was a need to include a stage between the translucent pupa and mature bee. To increase efficiency, I copied the drawing of the prepupa digitally, readjusted its shape and size to fit the next stage of development (as pupa) and colored it accordingly. I found it important to digitally add the brood food that the brood sits in and consumes in its cell. Photographs of the lateral view normally leave this out, presumably because the comb is cut in such a way that any paste spills over the edge. In all, the illustration covers 6 stages of bee development and includes a timeline for the worker bee [Fig 24].

A B



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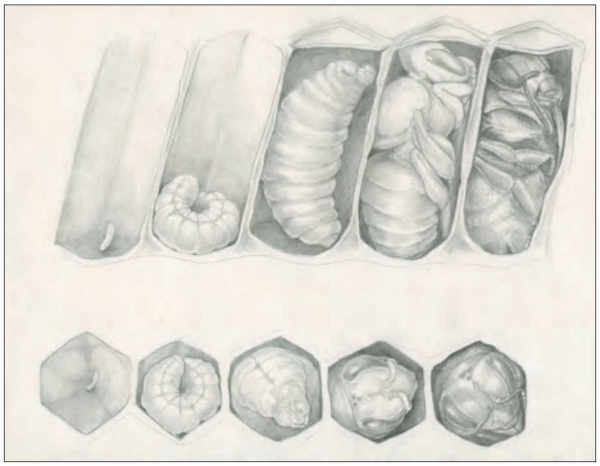


E

Fig 25:
A) Initial drawing;
B) First sketch attempt in sketchbook;
C) Second sketch attempt;
D) Initial color study in Adobe Photoshop;
E) Final drawing on drawing paper

chapter 3

THE HIVE

During my first hive experience I saw an array of covered cells, but they varied in texture, color and shape, including large sections that looked as if they were poured over with hot wax. Bees were climbing in and out of the cells, crawling all over the comb and making it hard to feel any sense of organization. From above, the contents of some of the open cells glinted in the sunlight, an indication of liquid, but they were dark and it was difficult to discern what was inside. There were varying levels of viscosity, opacity and color in these cells, and some even contained some blobs of white, which I soon found out were the brood in nectar baths (which serve as their food). Some cells looked like they were filled with a yellow jam, wet sand, milky jelly or dark honey. I found it difficult to later find visualizations to help me understand what I was looking at that day in the hive. It was after an extensive search of honey bee guides and references that I could compile the information I needed to understand. Hopefully, my work can present this information more readily for the beginner hobby beekeeper.

After that day, the next subject on my list of learning was finding out more about the honey bee home—from hollow trees, carcasses and skeps to the relatively more recent Langstroth Hive [pictured to both the left and right, and Fig 3]. The Langstroth Box Hive is probably the most widely used hive for beekeepers today, and is recognized by its layered, rearrangeable boxes (supers) containing 8-10 hanging, removable frames. The best colors and materials are debated by beekeepers, but they are most often made of wood and painted white to reflect the sunlight and protect the hive from overheating. There are many resources showing the specific dimensions and structure of a Langstroth hive, and I do not believe there is a need to add to the collection. However, what I found that could use some more attention is the inside of the hive.

COMB CONTENTS

Observing and understanding the comb contents and patterns is hugely important in determining colony health. One major indicator of a healthy hive is the queen's brood-laying pattern, generally described in the shape of an arc in a frame of the deep super, expanding from the middle frames to the outer frames [Fig 31]. If the queen's brood-laying is erratic, it can reveal an unhealthy queen [Fig 32]. Moreover, if a cell has multiple eggs within it, the hive's unfertilized worker population has taken over the role of laying, which does not bode well, either. Queen failure has been identified by U.S. beekeepers as the top reason that a colony does not survive the winter (vanEngelsdorp D. H., 2008). A visible progression of development should also be apparent in the brood pattern, from egg to capped cell, with the most developed toward the center where the queen begins. All pupae should be capped, and all of the caps should be without holes and convex, whether mildly (worker cells), intermediately (drone cells), or greatly distended (queen cells).

HEALTHY

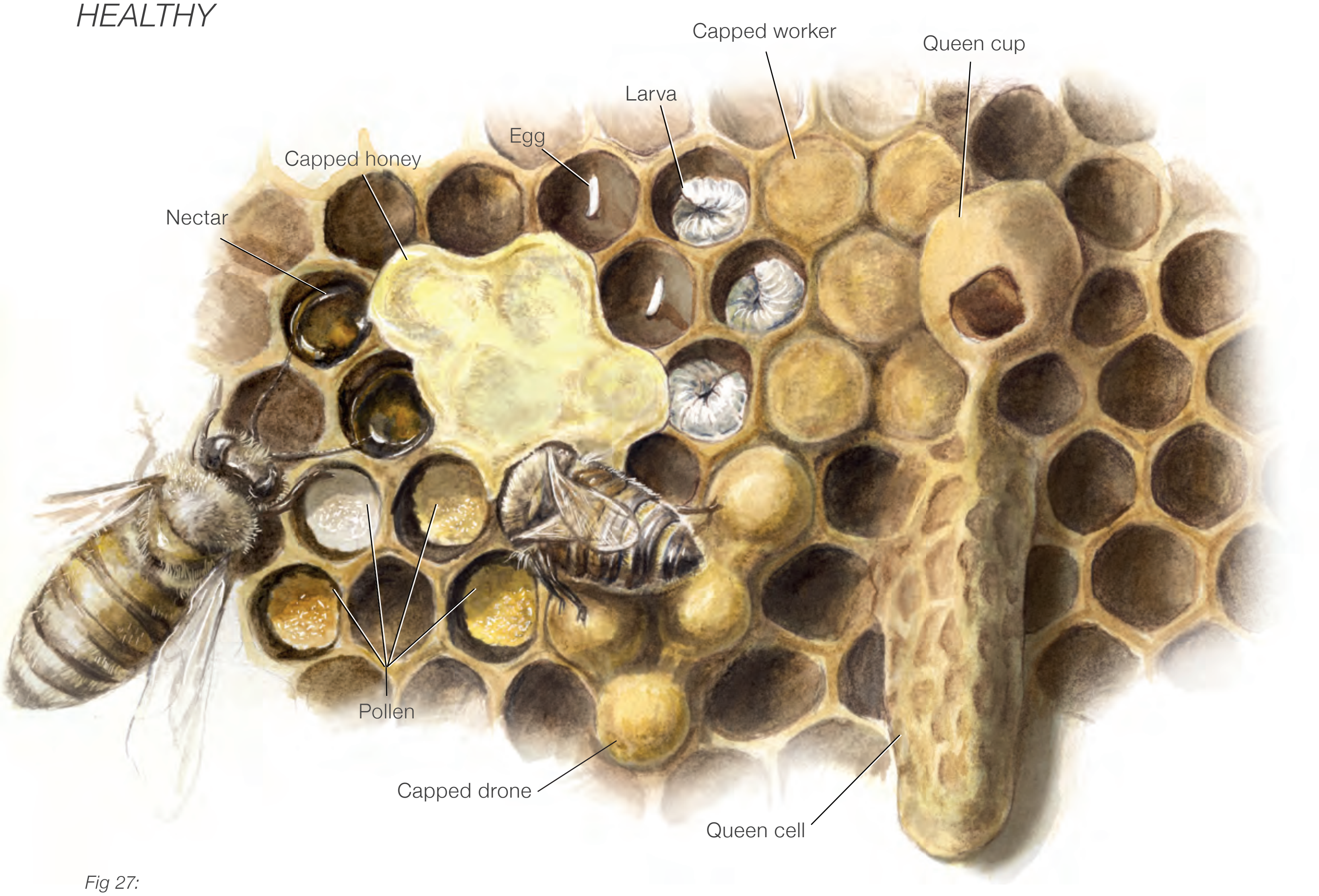


Fig 27:
Cell content identification

Another indicator of hive health is the number of cells/frames with pollen and honey storage, as well as the diversity in the nutrients' sources. Pollen is the main source of proteins and lipids for the honey bee, and adult worker bees primarily consume nectar, stored as honey and rich in sugar. The amount of food stored gives a good estimation of how prepared the colony is to feed the brood and survive the winter. In the U.S., starvation has been ranked second in reasons for winter mortality of the honey bees (vanEngelsdorp D. H., 2008). Furthermore, decreased foraging acts with disease and toxic pesticides to stress the honey bees (Naug, 2009), resulting in malnourished colonies with more susceptible immune systems. Like humans, honey bees require diversity in their food sources for well rounded nutrition. Thus, it is important that beekeepers know what their bees are feeding on.

Having a resource that helps the beekeeper clearly identify the cell contents and patterns is vital. I have found material that aids in identification, though I've found that the view is too far away for the learner to actually see and understand the contents, or, like the anatomy illustrations, they are often depicted in black and white. This distant perspective is most likely to show naturally occurring comb content variety, but it is ultimately quite unhelpful when discerning content. Additionally, the colors, clarity and texture of the contents are important indicators.

UNHEALTHY

Healthy comb will have healthy productive bees.

Darker comb indicates heavy re-use.

Many stressors show similar signs in an unhealthy colony , including, but not limited, to those pictured.

DISCUSSION

Cell Content Identification

One will not find every cell content possibility in the same frame, so many identification aids are not very comprehensive and may just show 2 or 3 potential contents in each image. For identification ease, I found it important to show this information in a complete manner. Furthermore, I believe that in order to promote colony health, it is important to describe what healthy forage and brood comb look like in direct comparison to the unhealthy potentials. This is not an overall pattern of health, but includes different specific viruses that may affect the brood, fungi that infect the bees and food storages, and other atypical cell contents. First, I made a list of both healthy and unhealthy types of cells that a beekeeper can find in their comb and drew quick sketches of what they might

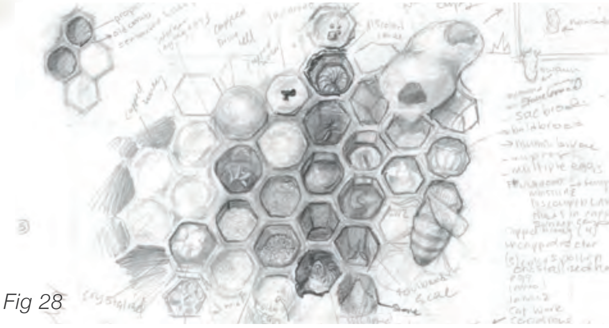


Fig 28

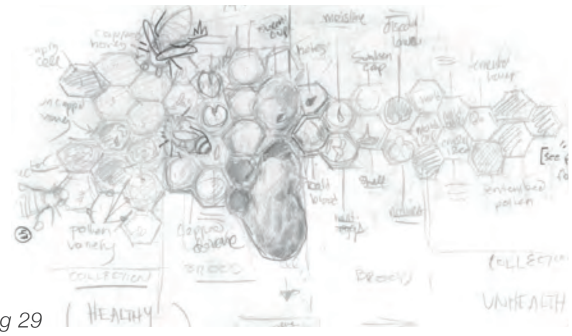


Fig 29

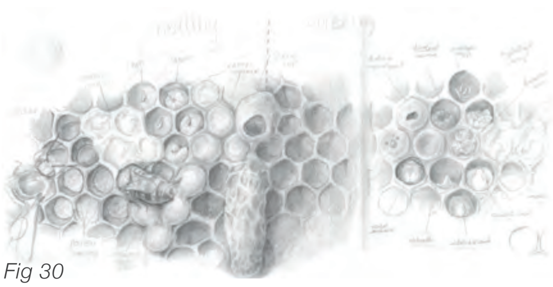


Fig 30

Fig 31

Healthy Brood

Note the concentric laying pattern where the most fully developed bees are located in the center of the frame and all brood is closely accompanied by good stores of food with pollen and honey.

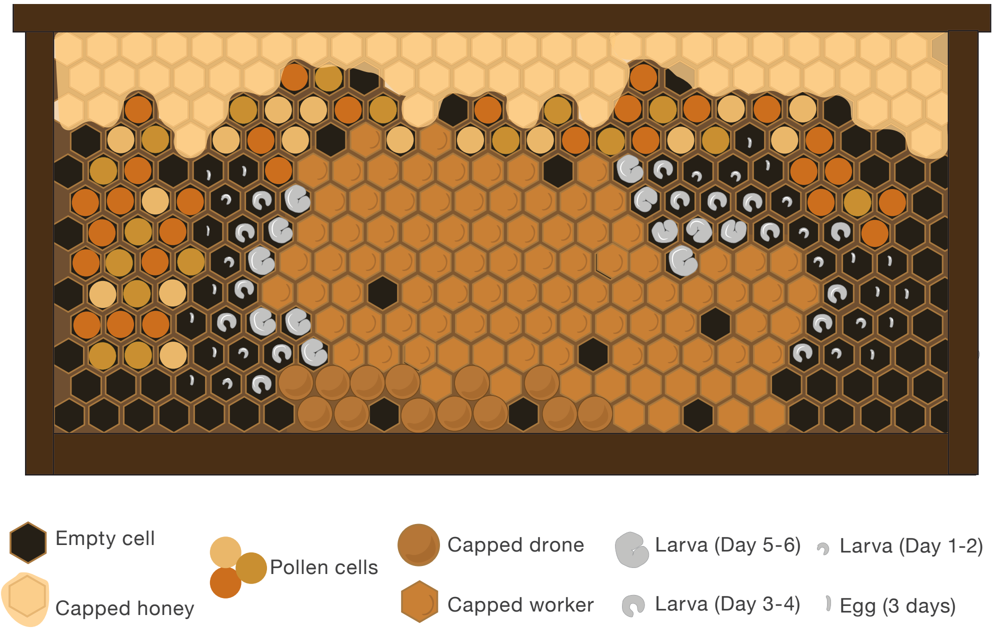
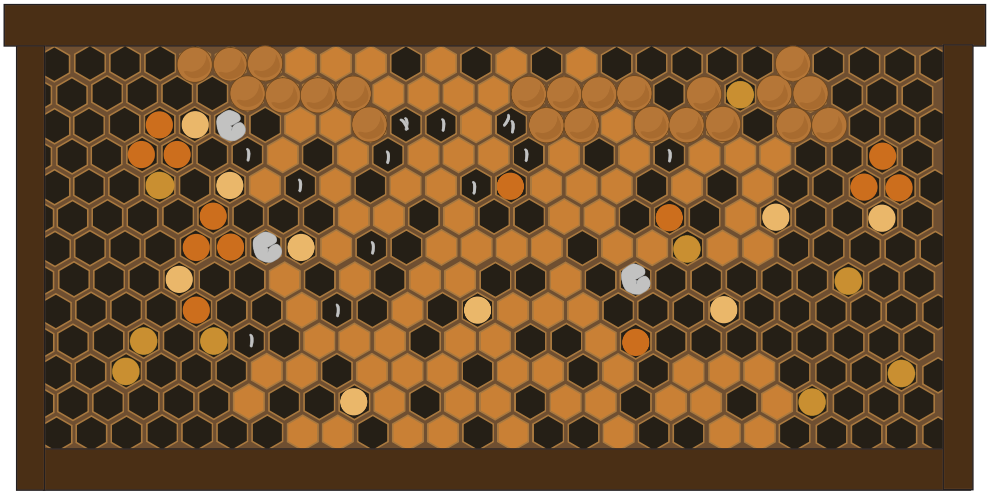


Fig 32

Unhealthy Brood

Note the irregular laying pattern, inefficiency of space, many drone cells and insufficient food stores for the brood. In addition, some cells have multiple eggs, which indicates worker-laying.



look like [Fig 28]. I found it important to show these cells from the same direct perspective that a beekeeper would have. Soon, I realized that the labeling in this original drawing would be disorganized and illegible, and the image needed more structure. I sketched a layout that would be conducive to multiple labels pointing to the interlocking hexagons [Fig 29]. In my final drawing, I traced a portion of comb I had previously photographed to recreate the pattern, size and shape of a natural comb. I decided to think ahead about the orientation of the illustration as it might be printed in the book and chose to use the natural crease at the spine of the book to be the division between the healthy and unhealthy comb. With this in mind, I rendered the comb in graphite as a precursor to a final watercolor painting [Fig 27].

To fully render the details of each cell, the drawing was scanned and printed at 120% of its original size and transferred to watercolor paper using a light box. The paper was then soaked and taped to a board to stretch and dry. It was my goal to keep this illustration very natural and organic, so I chose watercolor to be the foremost option to support this style, as there is a certain control yet spontaneity that these paints can provide [Fig 27]. After completing the painting, I removed it from the board, scanned it and digitally labeled it. It is my hope that this illustration can be used as a quick assessment of hive health when closely inspecting the comb.

Brood Patterns

My goal is to create illustrations that include all of the top features to check for in a visit to the hive in order to quickly measure hive health, including the use of color when it is a pertinent assessment tool.

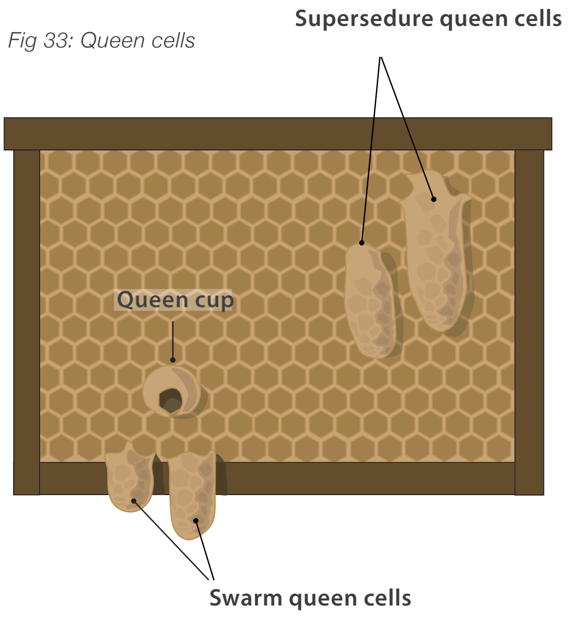
In my illustrations [Fig 31 & 32], I give a few quick examples of what is a normal brood pattern and what is irregular. I approached this by first repurposing the honeycomb pattern I created in Adobe Illustrator. I then created small graphics in Adobe Illustrator of the basic contents of the honey comb—honey as capped and covered with beeswax, pollen as multicolor circles, capped brood as a raised tan circle and small representations of larva and eggs. I decided to depict these graphically, as the focus of the illustration is about overall pattern identification. More detailed drawings of the cell contents would only distract-- and are described in greater detail in the illustration for cell content identification [Fig 27].

Using images of the frame samples from the Virginia Tech hives and the ensuing discussion with the beekeepers/entomologists that run the apiary, as well as a group of online guides, I determined what a healthy brood laying pattern would look like: consistent in an inward to outward arc of egg-laying and development, and supported with pollen and honey food sources to nourish the brood [Fig 31]. Every frame is different, but these healthy patterns are relatively consistent. It is natural to have a few empty cells, however, as shown in the “unhealthy brood” image [Fig 32], laying patterns that show an inefficiency of space are a great signal of an unhealthy queen or colony. Often there will be no clear or consistent pattern of development in the brood and insufficient food supplies. Indicators such as multiple eggs in a cell or an overabundance of drone cells can show that infertile worker bees are laying eggs in lieu of the queen. Both images include a key to describe the cell contents.

Queen Cells

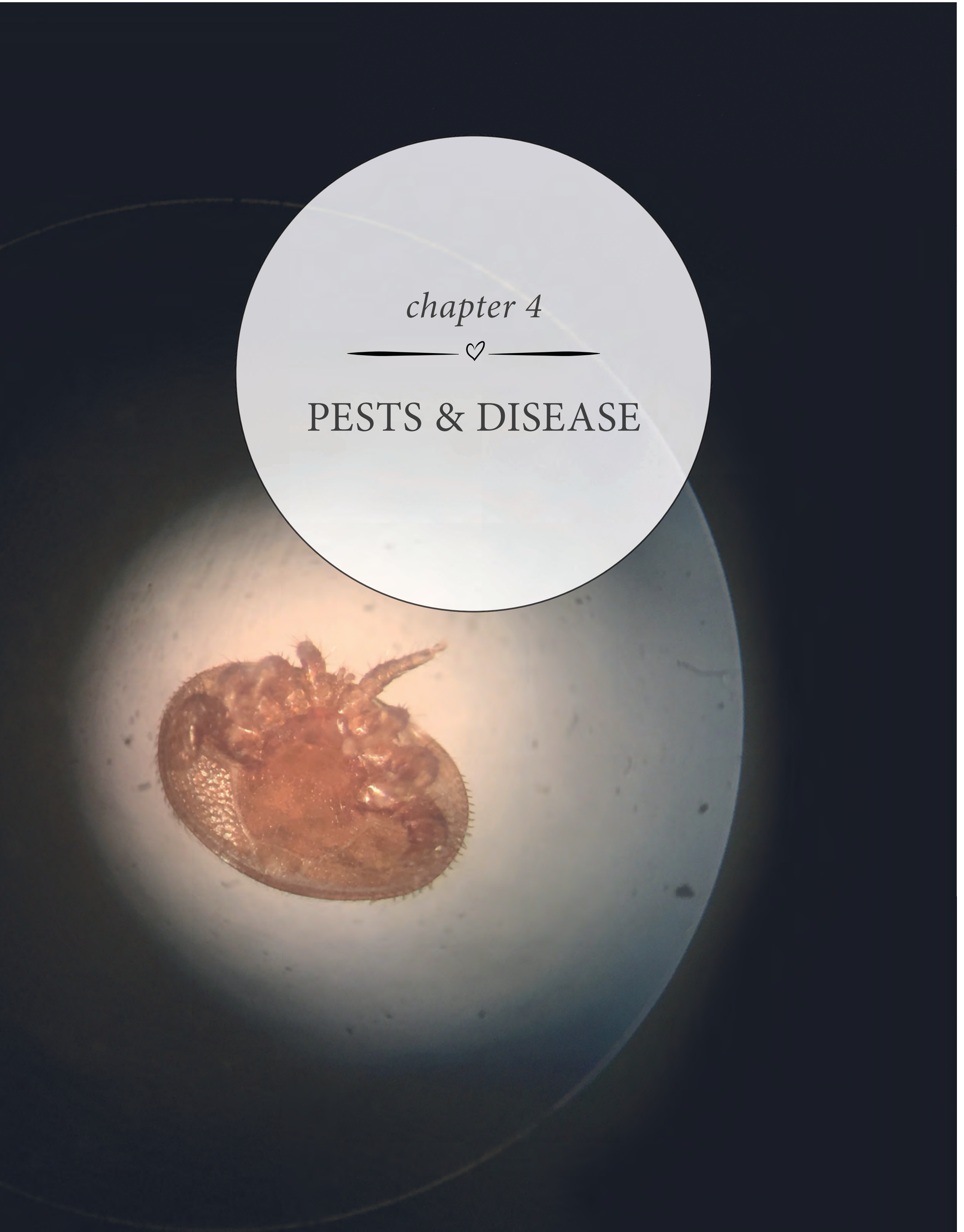
In addition to these brood guides, I added a small graphic of a hive frame indicating where beekeepers can find queen cells and what their position means. This explains the difference between a supersedure cell and a swarm cell [Fig 33]. A supersedure cell is often located near the center of the frame and is a tell-tale sign that new queen bees are being bred to replace the current queen. When the peanut shaped queen cell is hanging off of, or near the bottom of the frame, this means that the colony is soon to split up and swarm. Beekeepers do their best to prevent swarming by keeping the colony at a comfortable size and temperature, with proper ventilation. However, when the cells arise they can clip the queen’s wings, remove the queen cells or manually replace the queen.

Fig 33: Queen cells



chapter 4

PESTS & DISEASE



The beekeeper pulled out a frame and frowned. I stood there, scrutinizing the frame. It was covered with tons of crawling bees so…what exactly was wrong? I asked the beekeeper, and he began to point out details that, as a novice, I had missed. The bees were not complying with their natural tasks, but rather were frantically chasing out some small dark beetles over nearly empty comb. On the next frame over, the occupied cells were erratically scattered and some partially formed pupae were visible, left uncapped during their larval stage. Additionally, there were unusually large outgrowths on the edges of the brood cells, indicating new queens being laid for an upcoming swarm. There were a few wrong things happening in this hive, and I was only just beginning to understand what to look for.

HIVE INVADERS

There are numerous factors that influence the health and survival of the Western honey bee. These include pests, parasites, pesticides, bacterial and viral infection, fungi and larger (region-specific) predators. As previously mentioned, it is the interaction of these, with the addition of climate, nutrition and other external factors, that exponentially increases honey bee mortality. Guarding the hive is the final task of the honey bee worker before she leaves to begin her foraging duties, and it is a job only for a select population of worker bees. The honey bee can start this task as young as 7 days old and as old as 22 days. This normally involves antennation between the guard bee and the nest visitor, whereby the guard bee determines whether the incomer is a nestmate by assessing "the concentrations of an incoming bee's recognition cues and evaluate[s] them" (Breed, 2004). When a foreigner is found at the door, the patrolling guard bees emit an alarm pheromone and fan their wings to quickly spread the alarm throughout the hive. This encourages defensive behavior in the receptor bees, aptly named as "stingers," who attack and even pursue the unwelcome invaders (Bortolotti, 2014).

Varroa mites [Fig 36] are one of the worst intruders, sucking the hemolymph from adult and brood (especially drone brood), and quickly reproducing in the hive. Honey bees are able to detect these mites in their brood and remove both the infected brood and the mites from adult bees but not fast enough to prevent collapse (Spivak, 2001). It has been shown repeatedly that the *Varroa destructor* mite has been lethal by resulting in "malnourished, deformed and underweight bees" and by impairing the immune system of pupae, while transferring viruses such as DWV and Acute bee paralysis virus (ABPV) (vanEngelsdorp & Meixner, 2010). The synergy between *Varroa* and DWV has been "responsible for the death of millions of honey bee colonies

Fig 34: Life cycle of the Varroa during honey bee development

A fertilized female *Varroa* enters the larval cell 15 hours before it is capped

The *Varroa* feeds off of the prepupal haemolymph. After 30 hours, she lays her first egg-- a male. She continues to lay female eggs every 30 hours

Mating takes place within the cell 5-6 days after the cell is capped

Two days after mating, the first female deutonymph is born

After maturation, the bee leaves the cell with the female *Varroa* parasites attached. The male and immature *Varroa* are eliminated

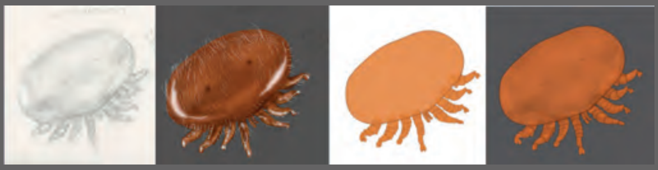


Fig 35

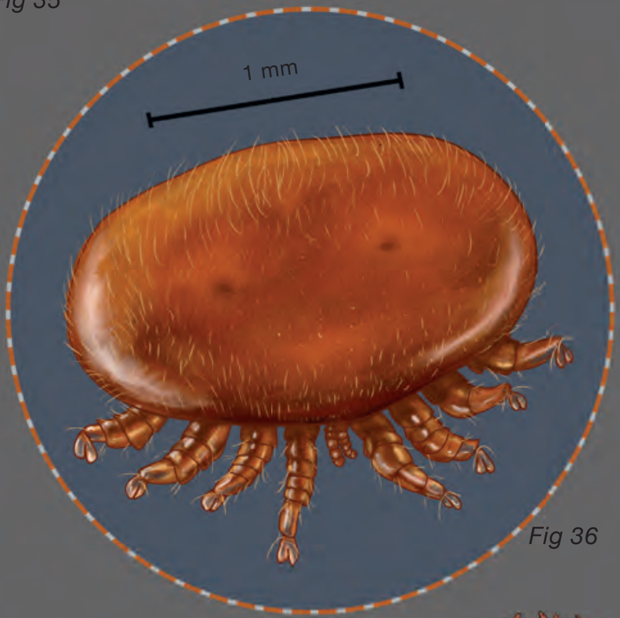


Fig 36

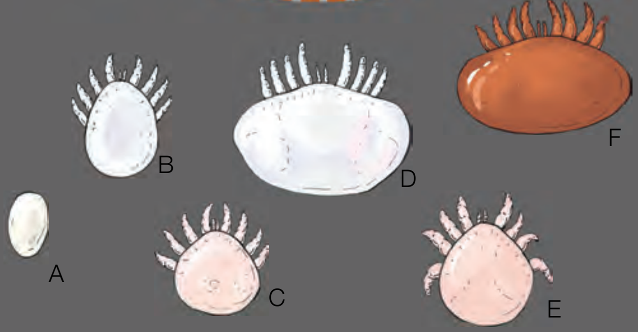


Fig 37: A-Egg, B-protonymph, C-male deutonymph, D-female deutonyph, E-adult male, F-adult female

Fig 38

and has become the most significant threat to apiculture worldwide (Zheng, et al., 2015)." Additionally, honey bees who have *Varroa* in the hive have increased foraging activity, causing them to stay away from the colony longer (Ellis & Delaplane, 2008). Among the other prominent pests are the comb-destroying Greater Wax Moth (*Galleria mellonella*) and the congesting, destructive Small Hive Beetle (*Aethina tumida*).

Varroa mites are heavily highlighted in the beekeeping community, and for good reason. There are many editorial illustrations explaining the impact and life cycle of the *Varroa* [Fig 35], but fewer direct resources for the hobby beekeeper. In my research, I looked for images that could answer the beekeeper's questions: How do you recognize a colony infected with *Varroa*? What are the symptoms in the adult bees? How can you check for *Varroa*? How do you prevent them? and How do you treat for them? *Varroa* specifically target the large drone brood, so when searching the hive for the source of infestation, often the drone brood is the first place to look.

The questions posed for the *Varroa* are also important to ask when assessing the hive for wax moth and hive beetle invasions. The presence of these two pests are often more obvious at first glance than *Varroa*. The greater wax moth leaves a silk web across the surface of the comb, the larva tunnels through the cells, and pupae burrow into the frames and boxes with tough white cocoons, all creating serious damage in the hive [Fig 42]. Additionally, they attack stored food and brood comb, eating pupae cases and larval skins. Hive beetles also eat stored food and brood, and their larva burrows through the brood comb. If the hive beetle population is too overwhelming, the queen bee will stop laying eggs. Hive beetles lay on average 30 eggs per cell, and the presence of the combined inhabitants in the hive, raises the internal heat to unbearable levels for the temperamental honey bees. Furthermore, a smell that has been described as "rotting oranges" is caused by the defecation of the hive beetle which ferments the honey, leaving it inedible for the colony (Sammataro, 2011) [Fig 46]. The stress of the occupation will "reduce colony bee populations, brood area, and flight activity (Ellis & Delaplane, 2008)." In *Natural Beekeeping: Organic Approaches to Modern Apiculture,* a book by Ross Conrad, former president of the

Vermont Beekeeper's Association, there is a wealth of information and relatively helpful color photographs on how to spot mites and pests in the hive. It also includes a table with a handful of symptoms and probable causes of other diseases and problems affecting the colony. Though, as stated in previous examples, it would benefit from visual aids to help beekeepers spot and understand these symptoms. Additionally, this book does not come without agenda, focusing on exclusively organic approaches in handling the hive, which may not be the most effective for all beekeepers. Still, at nearly 300 pages long, it is an excellent resource in describing what to look for when managing colony health, and it's an easy read for beginner/hobby beekeepers.

Other sources, like *Beekeeping for Dummies*, offer a list of questions to ask when opening the hive and looking for *Varroa*, as well as a couple of possible treatment options. However, this book has a similar problem with provided images: black and white or absent when needed. *The Beekeeper's Handbook* is another, well-rounded resource with wonderful illustrations and relatively up-to-date research. Along with the other available books, this is not a quick and easy field guide resource, but more of an easy to read comprehensive bee almanac. There are some guides available on the internet, but they are not consistently reliable and even misrepresent the pests enough that beekeepers may not be able to clearly identify them!

PEST DISCUSSION

I planned to create a visual representation of the effects of the most common pests—the *Varroa*, wax moth and hive beetle—as well as a detailed image of each pest and their respective, and equally destructive, larval forms. My original idea incorporated all three pests and their effects in one hive frame, in one image—however, the idea evolved in my quest to find the best way to convey the information. I decided to still use the comb, but individually in frames, to give a "snapshot" of what the comb will look like with the infestation. In developing these images, I was faced with the challenge of representing honeycomb in an engaging and organic manner. I decided it would be easiest to build the pattern

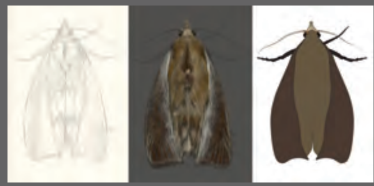


Fig 39

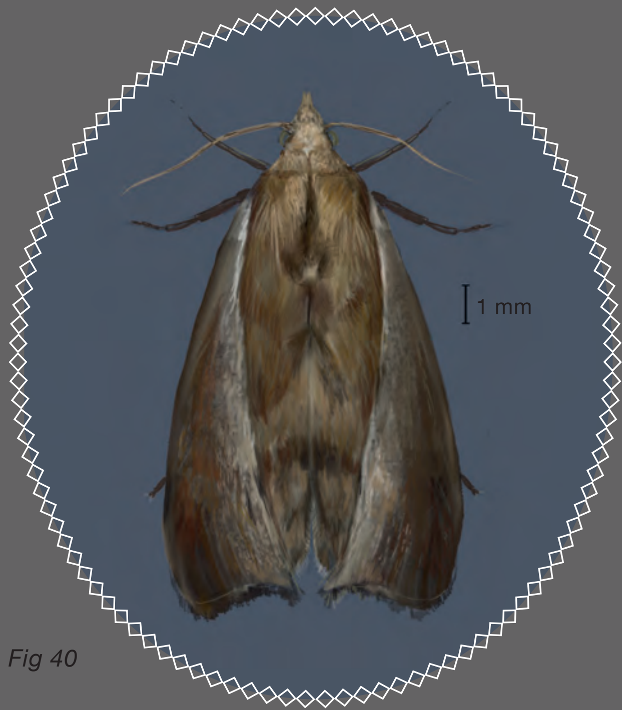


Fig 40


Fig 41


Fig 42

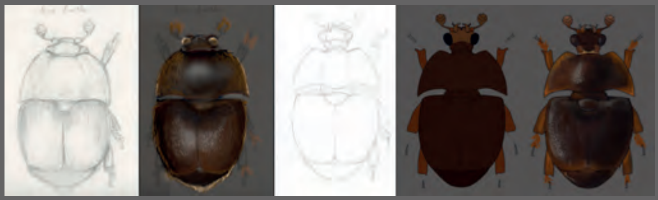


Fig 43

Fig 44

Fig 45

Fig 46

digitally, instead of spending three hours trying to measure 200 small hexagons equidistant from each other. I accomplished this by using the polygon shape tool in Adobe Photoshop, defined with six sides. I copied and dragged this hexagon to an approximately natural distance from the original. Then using the guidelines and an increasingly larger selection of hexagons, I multiplied the pattern until I felt I had enough for my image and then put it into perspective using the Transform tool [Fig 47A]. Then came the decision of the size. How small was too small to represent the comb? I changed the size and selection of the comb pattern until I decided it was sufficient for what I was attempting to represent [Fig 47B]. After beginning the initial tracing onto paper with this layout, my faculty member pointed out that it was not actually in a real perspective, but was merely skewed. We started over in Adobe Illustrator where I learned to use the Extrude/Bevel tool which helped me turn my flat pattern into a three dimensional form. This tool simply extended the honey comb pattern along the z-axis to give it depth and gave the option to control the angle at which it did so. With the perspective and angle I first chose, the cells furthest to the right became too "distant" to communicate their contents, and so I chose a more traditional one-point perspective. However, after tracing the cells onto drawing paper, I found this perspective to be too formal, so I spent more time with the perspective options in the Extrude/Bevel tool, resulting in a slightly angled, frontal superior view [Fig 47C]. Even with a realistic and informative perspective, the illustration still felt too factory-made, so I returned to Adobe Illustrator to incorporate the Warp tool, creating a more natural comb surface [Fig 47D]. I used this organic comb as a foundation for the two "snapshots" of pest invasion—the Wax Moth's web strewn and larval destruction [Fig 42] and the Hive Beetle's overflowing eggs and fermented honey [Fig 46].

I chose to represent each of the three pests in the form of family portraits. For the *Varroa* mite, I first drew sketches of the pest from my under-the-microscope inspection at the Natural History Museum Science Weekend in Maastricht at the beginning of October 2016, later combined with online resources. Then I scanned the sketch and did a quick color study with it in Adobe Photoshop. I traced the original drawings in Adobe Illustrator to more clearly define the structures and to choose base colors before bringing the Adobe Illustrator file into Photoshop, layering it with the original sketch [Fig 35] and then rendering it fully. I added a border for a little extra pizzazz and to convey a “portrait” to make the images more interesting and relatable [Fig 36]. In addition to the most commonly seen mature female, I also made small drawings of the egg, protonymph, male and female deutonymphs, and adult male and daughter. I then inked these drawings with rapidograph pens, scanned them and colored them digitally [Fig 37]. I decided to not fully render them because only the color and general shape are important, and I did not want to detract from the adult Varroa.

For the *Varroa* mite, I included an additional image detailing their infestation and parasitism of the honey bee brood [Fig 34]. To create this image, I used my previous bee development stages image as a base and did the line work in Adobe Illustrator. To give some dimension and indicate light, I blocked in color at the back of the cells. I created the *Varroa* mites in Adobe Illustrator, as well, and attached text to describe what was happening in the life of the mite [Fig 34]. *Varroa* mites also carry viruses, such as Deformed Wing Virus (DWV) and so I decided to create another image to show the results of their harmful parasitism. I used a series of reference images from both healthy honey bees and those with deformed wings to create this image of the honey bee inflicted with DWV [Fig 38]. I decided to make the final illustration in pen and ink, as I felt that the edges of the deformed wings were reminiscent of the dynamic lines created with dip pens. I scanned this image in and highlighted the wings and added a pesky *Varroa* mite nestled in the back of the adult bee’s thorax.

I approached the Hive Beetle and Wax Moth in the same way as the *Varroa*. I began with sketches from compiled resources [Fig 39 & 43] and scanned them. I made quick color studies of the two pests to see how I could best represent their unique colors and textures. Soon, I realized that the hive beetle was not well represented, as

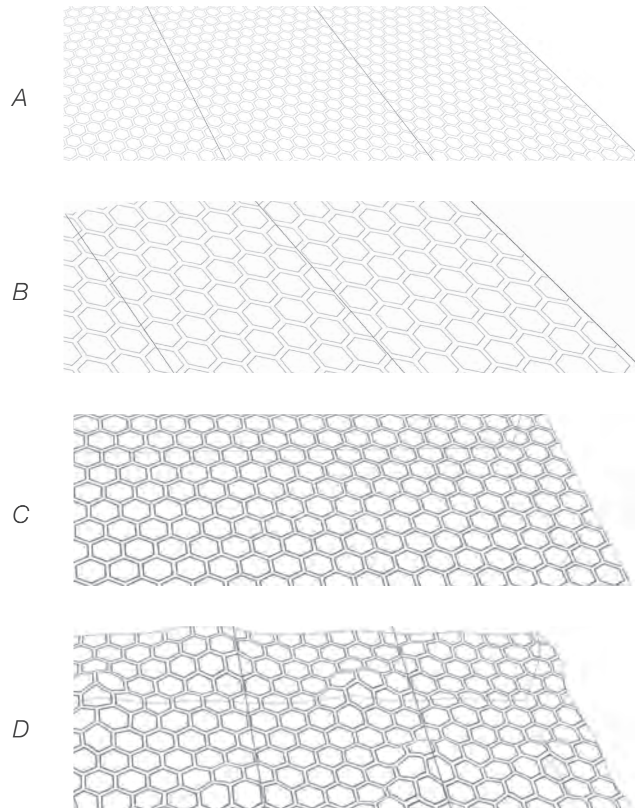


Fig 47

Fig 48: Visual symptoms of American Foulbrood, note the discoloration and slumped forms
Top: Left, Early stage infected prepupa; Right, advanced infected prepupa.
Bottom: Left, diseased pupa; Right, pupal scale

it was drawn in its most compact form and not its natural extended, mobile form. I redrew the hive beetle [Fig 39] and brought it, and the wax moth drawing, into Adobe Illustrator to outline their forms—mostly to define their appendages. Then I linked these line drawings to the original Adobe Photoshop color tests as a foundation for the intermediate rendering of the two pests [Fig 40 & 44]. I withheld some detail, knowing that these images would be small in the final production.

Next, I drew the damaging larval forms of both pests in graphite, later transferred to Dura-Lar (a polyester film) and inked with traditional dip pen line work. Then I scanned them in and multiplied them over a colored background in Adobe Photoshop to fit the aesthetic [Fig 41 & 45]. I chose a light, neutral color to represent the larvae's natural appearance without adding extraneous detail. I added white highlights digitally to give an indication of both form and juicy texture.

DISEASE AND DEATH

Honey bees, among their many other responsibilities, are excellent housekeepers. They maintain their hive's cleanliness and safety as best as they can by guarding the entrance from predators, leaving the hive to defecate (called "cleansing flights"), chasing out trouble-makers and sealing poisoned food supply (Sammataro, 2011). Honey bees also carry their sick and dying out of the hive, much like the lepers were cast outside the encampments of Israel in the wilderness (Numbers 5, *The Bible*, ESV). Detecting problems in a hive requires the beekeeper to engage all of their senses. The more time a beekeeper spends understanding this sensory input and how it relates to a healthy hive, the easier it is to detect when something is wrong. The group presence can be first evaluated by listening to the sound of the hive. If the hive is stressed or at low capacity, the beekeeper should be able to distinguish a difference in pitch or volume of the colony hum. Upon approaching the hive, the keeper should look for fecal staining, dead bees and/or infected brood littering the entrance and lethargic or deformed bees. Not only should sight and sound be engaged, but also noticing "when the faintly sweet scent that normally exudes from a hive becomes sour or foul," as this could be an indication of foulbrood, disease or fermenting honey (Conrad, 2013).

Devastating hive invaders can come in many forms beyond pests and parasites, including bacterial and fungal infection, viruses, and microsporidian disease. Of these, the most significant in the life of a Western honey bee are the bacterial infections *Nosema apis* and American Foulbrood (AFB) [Fig 48] as well as the fungal diseases of the brood that originate in the gut—Stonebrood [Fig 50] and Chalkbrood [Fig 51]. In addition are the viruses, Acute bee paralysis virus (ABPV), Sacbrood [Fig 49] and the aforementioned Deformed Wing Virus (DWV) [Fig 38]. Understanding how to identify these diseases early is crucial for preventing the colony's downfall.

Deformed Wing Virus [Fig 38] is the most common infection of honey bee colonies, due to its synergistic interactions with both *Varroa* and *Nosema*. The honey bee can be affected by the

Fig 49: Sacbrood Virus (SBV)

Fig 50: Stonebrood is caused by a fungal infection of Aspergillus fumigatus

Fig 51: Chalkbrood is a fungal infection of the brood caused by Ascosphaera apis.

virus even if it does not show wing deformity, by showing itself through “learning behavior, aggressiveness, and lifespan (Zheng, et al., 2015).”

American Foulbrood [Fig 48] is a plague of *Apis mellifera* any place in the world where they reside. It is an infection of the brood that is spread through spores of the bacteria *Paenibacillus larvae* that can remain viable for up to 80 years. After the spores develop in the gut of the honey bee larvae, the disease will move into the vegetative stage—the doom of the colony. Melted coffee colored larvae perforated, sunken and moisture-gathering cappings [Fig 27] are all characteristic of AFB, and the odor has been likened to the smell of rotting meat (Snyder, 2011). A common attribute in the pupal stage is the false protruding tongue and the dark, dried scales glued to the sides of the cells. AFB is so virulent that even today, the main form of treatment for a diseased hive is to burn it and all associated equipment (Sammataro, 2011). Therefore, it is very important to be able to identify this disease early.

Sacbrood Virus (SBV) [Fig 49] is when the larva fails to pupate and fluid builds up beneath their unshed skin. Eventually they dry out and darken, resulting in a “gondola-shaped” scale (Grabensteiner, 2001). Chalkbrood [Fig 51], is a fungal infection of the brood caused by *Ascosphaera apis* and Stonebrood [Fig 50] is caused by a fungal infection of *Aspergillus fumigatus*. The fungus thrives when brood is kept in damp, chilly conditions. In colonies that are already rife with pests and disease Chalkbrood can be severely damaging, though on its own it normally does not do more than reduce honey production (Sammataro, 2011). Thanks to the housekeeping of nurse honey bees, the mummified brood, though first found in the cells, can be found disposed on the bottom board at their various stages and colors of death (Sammataro, 2011).

There is plenty of information about these diseases, and research is continually being done to learn more about their interactions, consequences, prevention and treatment. Color and texture are especially important in describing the effects of these diseases, and are the primary things I looked for when researching. Articles often showed lateral views of the infected larvae, especially with AFB, but while good at explaining the disease, this perspective is not as helpful for identification purposes. Moreover, there are many black

Fig 52

and white illustrations and photos with color descriptions, which could be better conveyed if the images were simply in color. Lastly, many photos are not detailed enough for identification. A slumped and bloated tan larva pictured from far away could easily be mistaken for a light pollen packed cell.

DISEASE DISCUSSION

The illustration I've provided includes examples of form, texture and color of infected American Foulbrood [Fig 48], with an additional description to help with identification of honey bees in both the prepupal and pupal stages. As with most illustrations, I first drew this in graphite and later rendered it in a combination of watercolor and colored pencil. I felt it was important to get the colors and textures correct, so after scanning, I bolstered the colors and highlights in Photoshop.

In my second image, I depicted the commonly disposed of dead brood-- the viral Sacbrood [Fig 49], and the fungal Stonebrood [Fig 50] and Chalkbrood [Fig 51]. Each of these three has a very unique and specific texture. I first drew them in graphite, to help me better understand their form, and then transferred these drawings to watercolor paper. I experimented with a few techniques and materials to result in the rough, irregular texture of the chalk and stonebrood mummies [Fig 52]. This included a combination of splattering white gouache and using a drybrush technique in the stonebrood, and combining colored pencil, watercolor and white chalk to create the texture of the chalkbrood. To represent the sacbrood, I first painted this drawing in watercolor and then added specular highlights digitally. I then created a tweezer tool in Adobe Illustrator to contrast with the organic painting of the sacbrood.

CONCLUSION

I conducted an extensive review of the literature, but there is yet an abundance of information available for hobby beekeepers. Due to the global importance of these pollinators, information is vast and knowledge continues to grow as more research studies are conducted on the honey bee. As someone with the perspective of a hobby beekeeper, I have been overwhelmed. This overload of information and images has created a need for a concise and comprehensive guide for beekeepers, with a higher standard for visuals. My thesis adds to the bodies of knowledge in illustration and scientific literature, and works toward the goal of creating an engaging tool for hobby beekeepers to use in colony evaluations, while heavily engaging the senses. This tool, only yet conceptualized, should be as hands-on as the work it describes—with images aimed to explore the depths of color, texture and form in the natural world of the honey bee. Despite the underlying focus on sensorial experience, I was limited to visuals and written description. However, I would love to experiment with other sensory input within a public education setting. This research has opened numerous doors for subsequent research, as many subjects involving *Apis mellifera* were not breached in this thesis, such as the importance of the environment, pollination, wild bees as supportive pollinators, pesticides, land use, internal anatomy and physiology, and countless intricacies of honey bee communication. What drives us to protect the honey bees is a major concern—for our hives, our economy, our crops but ultimately, I think, because we see a little bit of ourselves in the honey bee.

In this exploration of apiculture, I have discovered a greater passion for the assiduous honey bees, and an even greater desire to share with others the intricate workings of their society. We need to engage with the bees and understand their struggles before we attempt to help them survive the new and old stressors of today's world.

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TERMS TO KNOW

Apiary – A place where bees are kept; a collection of hives

Apiculture – beekeeping

Brood – the young stages of honeybees (egg, larva and pupa)

Colony – a community of honey bees that live together

Colony Collapse Disorder (CCD) – "phenomenon that occurs when the majority of worker bees in a colony disappear and leave behind a queen, plenty of food and a few nurse bees to care for the remaining immature bees and the queen."

Corolla – petals of a flower

Entomologist – an expert on insects

Eusocial – highest organizational level of animals; caste system and non-reproductive members care for offspring

Forage – a wide search for food/provisions; the honey bee's search for nectar and pollen

Hemolymph – a fluid found in invertebrates, like the bee, that is analogous to blood and provides nutrients by direct contact to living tissue.

Hive – the nest or structure containing a colony of bees

Honey stomach – modified esophagus (synonymous with the crop) for honey storage

Hymenoptera- The Order that bees, wasps and ants are classified under.

The Western Honey Bee is classified as follows:

Kingdom – Animalia,

Phylum – Arthropoda

Class – Insecta

Order – Hymenoptera

Family – Apidae

Genus – *Apis*

Species – *Apis mellifera*

Inflorescence – the complete flower head of a plant, often including multiple flowers

Larvae – active immature form of the honey bee; does not yet have bee-like characteristics

Monocultures – producing a single crop at a time

Nectar – the sugary liquid produced by plants

Proboscis – tubular mouthpart of an insect, extended for sucking the nectar from flowers

Propolis – a resinous "bee glue" produced by mixing bee saliva and beeswax with plant sap

Skep – a woven beehive (often straw, wicker or wood)

Super – a box of a traditional Langstroth hive, containing 8-10 frames of comb

WHAT'S THE BUZZ WITH HONEY BEES? Illustrating Beekeeper Management

Skye Young

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