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THE GARDEN OASIS: Observations in a Southern California Garden

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Introduction

A garden can be a special place of relaxation and a corridor from which one can connect with the natural world and observe the complex relationships among the many organisms that make it their home. These organisms include a vast array of insects that contribute to the diversity of even the smallest garden.


Figure 1:Terracing the hillside pond. Photo credit: C. Tankersley.

We purchased an unassuming house in a quiet Southern California suburban neighborhood that included about half an acre of property made up of mostly lawn and a dense menagerie of backyard shrubs and trees on a steep hillside, along with a pond that was in desperate need of attention. The property had great promise, although not without some significant work to restore the long-neglected landscaping and expand the planting areas for new plants. The first stage in the transformation involved the complete removal of the backyard lawn. This was replaced by multiple, large, curved planting beds with gravel paths that nicely tied into the already existing patio. Many of the original plants and trees, especially those on the hillside were severely distorted or dead due to girdling by abandoned staking and rope left on the scrubs and trees. Most of these plants had to be removed. Since much of the hillside included steep sections and poor chalky soil, the addition of significant amounts of organic compost and soil amendments were necessary, which was followed by building numerous natural stone walls of

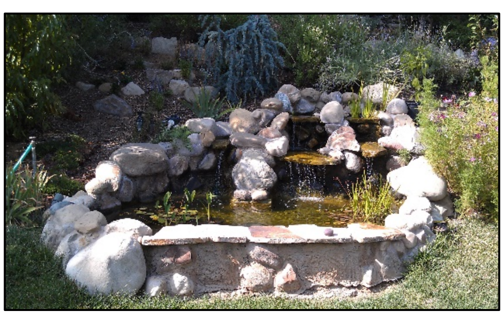


Figure 2: Early view of pond. Photo credit: C. Tankersley.

varying heights. This created new terraces available for planting and reduced the possibility for erosion. The total amount of stone was approximately 10 tons, and all of it was hand carried up the hillside.

Finally, the garden was thoughtfully planted with an assortment of annual and perennial plants along with deciduous and evergreen trees to create a landscape design arranged in layers of staggered heights. The term ‘garden’ refers not merely to a planting of vegetables, but the entire landscape with large groupings of the same species arranged to create a blended view of unique textures, shapes, and colors.

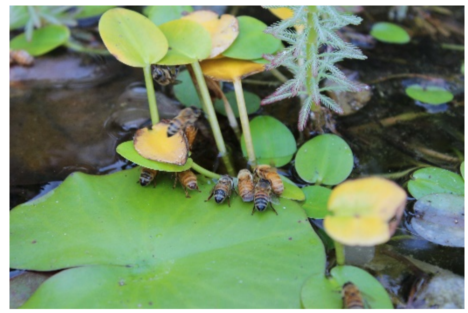


Figure 3: Honeybees gathering water. Photo credit: C. Tankersley.

One of the focal points in the garden was a large oval pond and two-tier waterfall that included its own selection of plants, including water hyacinths and irises that occupied the pond edges and water lilies, water lettuce and duckweed that spanned the water surface. The pond enhanced the garden with unique dimensions of beauty and calm that arose from the mesmerizing sounds of trickling water and the reflection of light off the water surface. The pond teemed with a variety of animals drawn to the watery habitat. Toads and frogs were established residents sharing the pond with a few small koi, but many birds and mammals also used the pond as a frequent watering spot. Insect activity at the pond could be frenetic at times depending on the time of day and

Figure 4: Frog on pond lily. Photo credit: C. Tankersley.

temperature. Damselflies and dragonflies were frequent guests at the pond, and one species of dragonfly in particular, a Flame Skimmer, regularly used the pond as a base from which he maintained a persistent lookout, flying back and forth regularly around the pond periphery. As the weather warmed, honeybees would gather in large groups and line the edge of pond lilies to drink while dragonfly larvae sat almost motionless in the litter at the bottom of the pond. The behavior and activity of insects in and around the entire garden provided a continual source of tranquility, learning and enjoyment.

In addition to their beauty and mystique, insects also serve many valuable and vital functions in garden and natural habitats that are often underappreciated. Plant propagation, such as pollination and seed dispersal may be the most recognizable benefit, but another essential role involves nutrient recycling. Insect scavengers consume and digest plant and animal waste to create basic organic materials and combined with the soil excavation by other insects, exposes these nutrients for use by various other animals, and importantly, plants. (Gullan and Cranston 2014) Insects also serve as important model organisms in a variety of research endeavors. The fruit fly (*Drosophila melanogaster*) has been at the core of genetic, behavioral, and molecular biology research for decades. Still, other insects such as beetles (Coleoptera), which represent the largest order of all insects with almost 400,000 described species, have now become increasingly important models for environmental and biomedical research. (Capinera 2006) Many novel chemical compounds isolated from insects have demonstrated potential utility in cardiovascular, immunological, and oncology research that may ultimately benefit people. (Cherniack 2010) Finally, it is well recognized that insects represent an important, and in many cases the sole food source for vertebrates, including birds, fish, and mammals.

For many centuries, people have also relied on insects as a readily available and nutritious source of food. Insects commonly consumed by people include beetles, caterpillars (Lepidoptera), bees, wasps, and ants (Hymenoptera), and grasshoppers, locusts and crickets (Orthoptera). As the global human population continues to grow, the demand for a sustainable, high quality protein will intensify and insects may provide a sustainable solution.

Of course, many insects are carnivorous and feed on other insects. An estimated 25 percent of all insect species are considered predatory or parasitic in their feeding habits and this supports an invaluable means of natural insect control. (Capinera 2006) These crucial roles of insects rely on a complex and interconnected set of relationships between insects and other organisms. Because insects represent such a large, overall biomass, they are considered the most significant and important link between other organisms as part of the overall food web. Naturally, with this diversity arises many of the pestiferous insects that can challenge even the most experienced gardener. However, in the chapters to come, I hope to illustrate the value of creating a diverse and balanced garden habitat inclusive to all insects and present mechanisms to overcome the challenges posed by insect pests. I will also present some of the insect interactions that have been observed over the years that have led to a greater understanding and appreciation for the biodiversity that can be cultivated in a garden through thoughtful yet simple efforts. A habitat focused garden is the best means to support a diverse and healthy habitat for wildlife, including insects, while also improving upon the outdoor living space for people. Over time and after careful planning and patience, our outdoor space was ultimately transformed into more than just a beautiful landscape, it became a fully functioning and species diverse habitat and ultimately a garden oasis.

Chapter 1 – Mantis and Honeybee


Figure 5: Bee hives at top of hill. Photo credit: C. Tankersley.

The first two creatures in the garden story are likely the most recognizable – the mantis and the honeybee. Mantises have consistently occupied the garden for many years with females often laying egg sacks called ootheca every year on many of the plants in the garden and potted citrus located on the patio. The honeybees were added to the garden in the form of two beehive colonies placed along the back edge of our property around 300 ft away from the house at the fence line and top of the terraced hillside. The respective roles of pest control and pollination by the mantis and honeybee are readily known, yet for some people these insects can also be intimidating and may elicit some amount of anxiety or fear.

There are many different species of mantises found throughout the temperate regions of the world. The mantises commonly observed in gardens of the western US, include two species, the introduced European Mantis (*Mantis religiosa*) and the native California Mantis (*Stagmomantis californica*). (Powell and Hogue 1979) Mantises are in the order Mantodea and includes a large group of over 2,300 species worldwide. (Svenson and Whiting 2004) Many of the now commonly found species in North America are considered invasive, with concerns that they are outcompeting and displacing native populations of mantises. The Chinese


Figure 6: California mantis (adult). Photo credit: C. Tankersley.

mantis (*Tenodera sinensis*) is one such introduced species that is commonly found in pet stores and is an iconic representation of the mantis, with specimens reaching almost five inches in length. Most mantises display some form of cryptic coloration that allows them to camouflage with the foliage and environment, but many species, especially those native to tropical habitats can take on an almost fanciful appearance to resemble plants and flowers in effort of attracting pollinators as prey. (Gullan and Cranston 2014)

People are both intrigued and fearful of the mantis given their menacing posture and odd, undulating walking behavior. Mantises have an almost alien looking triangle shaped head that coupled with spikes on the forelegs called tibial spines, present a formidable and menacing looking insect, but they can easily be handled without issue.

Mantises are frequently referred to as 'praying' mantises due to the way the insect clasps their raptorial forelegs together while at a resting position as if they are praying. Mantises have three simple eyes located between two large compound eyes each with multiple lenses that permits detection of very small movements. (Triplehorn and Johnson 2005) The compound eyes provide the mantis with binocular stereopsis, or stereo vision that allows for triangulation to accurately calculate the distance to prey. Their excellent peripheral vision, the ability to swivel the head 180 degrees, along with an almost lightning-fast precision, makes the mantis a very skillful hunter. (Triplehorn and Johnson 2005) Many mantises possess wings, but typically only the males are adept at flying any significance distance. Mantises will patiently wait motionless for a potential meal that

Figure 7: Immature *S. californica*). Photo credit: C. Tankersley.

may include not just insects, but frogs, lizards, hummingbirds, and other small birds. They are opportunistic creatures that use an ambush strategy to catch prey and will frequent areas where prey has been plentiful whether under a lamp post where moths may be attracted or near the flowers of citrus tree frequented by honeybees gathering nectar and pollen.

After mating, the female mantis will lay an ootheca or egg case resembling a frothy mass that looks like eggs whites. The female will affix the ootheca to a solid surface in a sheltered location and it will harden into a protective case containing several hundred eggs. (Gullan and Cranston 2014) Mantises undergo incomplete metamorphosis such that the young, called nymphs, appear like small-scale, wingless versions of the adults that emerge from the ootheca in about 3 to 10 weeks when temperatures are sufficiently warm. (Capinera 2006) Depending on the species, mantises may shed their old skin, or molt as many as ten times before reaching adult size and sexual maturity.

The other character in this chapter is the common European honeybee (*Apis mellifera ligustica*). Honeybees are in the order Hymenoptera and are best known for their critical roles of crop pollination, and honey and wax production. There are over 20,000 known species of bee worldwide with about 3,600 considered native to the US, yet less than 2 percent are honeybees or bumble bees. (UM Bee Lab) These insects come in an amazingly diverse range of colors, sizes, and shapes. Many bees are eusocial, like sweat bees, honeybees, and bumblebees that is defined by group living, cooperative care of young, reproductive division of labor, and overlapping generations. Many more bee species are

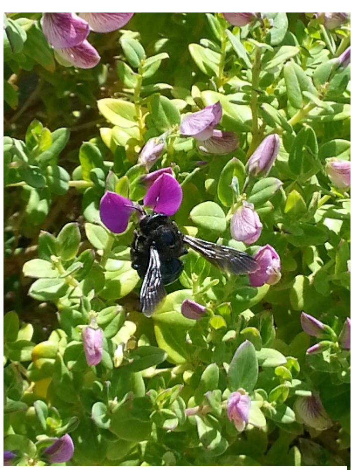


Figure 8: California carpenter bee (*Xylocopa californica*) on *Polygala fruticosa*. Photo credit: C. Tankersley.

completely solitary. Many bees do not sting and while the domestic honeybee may be acclaimed for its pollinating ability, many other bees like bumblebees and mason bees are more effective pollinators. My introduction to beekeeping began as a pre-teen led by a very wise neighbor, who was both an avid gardener and beekeeper. I cannot count the number of loads of cow manure from the local dairy that he and I loaded into his workhorse Chevrolet El Camino, then moved by wheelbarrow into his sprawling garden. The manure would often reach depths of three feet in areas. He was not only a wealth of knowledge about gardening, but his knowledge of beekeeping and importantly his calm demeanor around the bees was inspiring especially for a kid. However, the most vivid takeaway was his overall respect for the honeybee and his resolute attitude on importance of bees as pollinators. He had a calmness about him when working with the bees, which in retrospect is difficult to achieve, but important when working with honeybees as they can sense anxiety and stress that can unnecessarily cause them to become agitated. I remember fondly his demonstration of beekeeping tasks, including the all-important hive inspection. The process first involved opening the outer and inner hive covers, then carefully removing each frame from the hive supers. The frames are often sealed to each other and to the hive super by propolis, so it can be challenging pulling the first few out of the hive. The frames were often full of honey and completely covered in honeybees. Propolis is a very sticky substance produced by honeybees and made from plant resins collected by honeybees. Honeybees use propolis as a sealant to close off openings in the hive from weather and drafts.

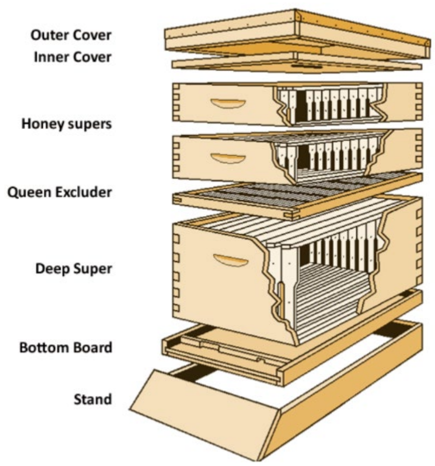


Figure 9: Standard Langstroth hive. Image from Almanac.com and D. Cushman.

Propolis has also been found to have an array of antibacterial, antifungal, and antiviral qualities. (Marchese 2009) In 1851, Lorenzo Langstroth, a Philadelphia minister, discovered that honeybees would not build excessive wax comb or propolis if the interior spacing of hive components are kept between 3/8 and 1/4 inches. (Beekeeper Bible 2011) By using this knowledge of bee space, the concept of the Langstroth hive was born permitting a modular hive design with frames hung vertically allowing routine access for honey collection and hive inspection. The Langstroth hive revolutionized beekeeping in the 19th century and most hives in use today are of this design. (Beekeeper Bible 2011) The hive supers come in various depths, deep usually containing brood, medium and honey supers containing a mixture of brood, honey, and pollen. Each super contains either eight or ten individual frames with foundation on which the worker bees build a wax comb structure in which the queen can lay eggs and pollen and honey can be stored. The nectar is transformed in the honey stomach of foraging worker bees by enzymes that convert the complex sugars in the nectar to simple sugars in a process called inversion. After returning to the colony, foragers regurgitate the modified nectar to younger bees where additional enzymes continue the process. Only after the water content reaches about 20 percent will the inverted nectar be deposited into a cell of the honeycomb. (Beekeeper Bible 2011) Through a process of evaporation assisted by bees flapping their wings inside the colony, individual cells full of the sugar liquid eventually become recognizable honey that are then

Figure 10: Honey comb being filled with processed nectar. Photo credit: C. Tankersley.

capped with a wax covering. It takes about 12 worker bees to eventually produce a teaspoon of honey. The honey is the food source for the colony. It is important to regularly examine the pattern of eggs, larvae, honey and pollen stores in the frames in order to assess the overall health and activity of the colony. This permits the beekeeper to make informed decisions on essential hive maintenance such as providing a growing colony with extra space by adding supers or adjusting the location of frames in the colony, or when necessary monitoring and treating for diseases, including the ubiquitous honeybee parasite called varroa mite (*Varroa destructor*). Some 43 years later, I would embark on my own journey into the fascinating and sometimes frustrating world of beekeeping with my first two colonies of honeybees. They were purchased as two separate, three pound 'packages', each consisting of a wooden screened box containing about 10,000 bees plus a separately caged queen bee suspended within each box. An upside-down punctured can of sugar water was also inserted into the box providing a source of food for the assembled bees that fed it to the queen bee. The packages are fashioned by gathering worker bees taken from various hives/colonies and placed by weight into screened wooden boxes. Mated queen bees are then enclosed in small screened rectangular cages, suspended at the top of each wooden box, so that they are isolated from the worker bees. This allows the worker bees to gradually acclimate to a pheromone secreted by the queen bee scent known as queen mandibular pheromone (QMP). (Beekeeper Bible 2011) If she were not

Figure 11: C. Tankersley wearing his new suit. Photo credit: C. Tankersley.

Figure 12: Bee package atop empty super. Photo credit: C. Tankersley.

initially isolated, the worker bees would likely sting her to death, since at least some of the worker bees may not recognize her as 'their' queen.

Worker bees are all female and normally their reproductive organs are suppressed by the presence of QMP from a healthy queen bee. Worker bees are continually in tune with the physical condition of the queen bee. In the event the queen bee's health fails or she dies, the concentration of QMP in the colony will subsequently decrease that will permit the ovaries of some worker bees to enlarge and become active. (Beekeeper Bible 2011) These worker bees will lay eggs that ultimately can become new queen bees that will depart the colony to mate with drone bees. One or more successfully mates queens will return to the colony to reestablish the healthy functioning of the colony. However, a colony can have only one queen bee, thus if more than one mated queen were to return, a battle would ensue with the loser often stung to death. Pheromones are essential to almost every aspect of colony function, including driving development and reproduction, foraging, defense, and ensuring an overall integration of activities within the hive. (Beekeeper Bible 2011)

On a warm March day, I carefully poured the worker bees from each of the packages into their own newly assembled 8-frame Langstroth hives. The small boxes containing the queen bees have a small 3/8-inch hole blocked with a cork, so I carefully replaced the small corks with small marshmallows. This will block the queens from immediately entering the colonies and help prevent injury during their assimilation. The worker bees will eat the marshmallow and eventually release the queen bees. Each small box containing a queen bee were then placed into their respective new hives by inserting the small boxes between frames at the top hive body.

Over a period of weeks, the honeybees successfully accepted their new homes and began foraging flights. Hive inspections revealed the presence of laid eggs and accumulating nectar being stored in drawn out honeycomb and the adventures in beekeeping was launched.

The garden was purposefully planted to support the common pollinating insects found in Southern California that include numerous species of social and solitary bees, including the newly arrived honeybees. Further, the species of flowering plants were selected to extend the availability of pollen and nectar sources throughout the growing season. Honeybees will forage as far as five miles from their colony to gather sufficient food; however, because of the number and variety of flowering plants within the garden, including numerous species of salvias, lavender, yarrow, bottlebrush, borage, rosemary, and fruit and citrus trees, I like to think that they stayed preferentially close by.

The Interaction

Honeybees have an extraordinary ability to locate sources of food and quickly communicate information on the location and quality of the food to the other foragers through what is known as the waggle-dance.[1] This complex dance conveys the location and distance to the food relative to the hive and the sun's position. The best nectar opportunities are typically available in the first few hours after blossoms open that is determined by the flowering cycle of the plants (called anthesis). The quality and quantity of nectar available to pollinators is also highly dependent upon on the ambient temperature and humidity. Honeybees take full advantage of this diurnal rhythm and

Figure 13: Flowering citrus.
Photo credit: C. Tankersley.

adjust their foraging activities across various flowering species throughout the day. Honeybees often develop preferred nectar sources and visit flowers with what they consider to be the best nectar, but they are also opportunistic and will exploit certain convenient sources of nectar when available. This can be easily observed by placing a shallow tray of sugar water outside for access by honeybees. It will take only a short time before the entire tray will be covered with honeybees that develop and almost frenetic behavior.

The garden was comprised with a variety of different citrus trees, some planted in pots and others in the ground. A kumquat in flower was the backdrop for the interaction of the honeybees and mantis. Citrus varieties planted throughout the garden included Eureka and Meyer lemons, a Persian 'Bearss' lime, clementine and Satsuma mandarins, navel and Valencia orange trees, and two varieties of kumquat.

tree. The benefits of growing your own citrus are many. Citrus fruit can remain on the tree for an extended period thus, the garden can effectively become the grocery store with the fruit harvested whenever needed. However, the benefits of your own citrus extend beyond the obvious fruit, because the exquisite fragrances that can saturate the air are truly intoxicating. It is said that such fragrances can boost a person's serotonin levels and release stress. Another important feature of having citrus in the garden is that it helps extend the availability of nectar and pollen later in the season after other flowers have died back.

Figure 14: Harvested and peeled citrus from the garden. Photo credit: C. Tankersley.

One early morning the honeybees were busy collecting nectar and pollen from flowers of the Satsuma mandarin when I noticed a California mantis in a strategic position near a group of the flowers. Exhibiting classic predatory behavior, the large light green colored female mantis was motionless assuming a stalking position waiting for a potential meal. The mantis did not have to wait long as an unsuspecting honeybee going about her business of foraging soon found herself in striking distance. In a flash, the mantis extended its raptorial legs with great precision and seized the honeybee, clutching it between the tibia and femur and secured by tibial spines, hooks, and claws. Though the honeybee struggled and attempted to sting the mantis, it was in vain as the mantis immediately commenced to feeding on the head with ravenous speed. This did not impair the involuntary stinging reflex of the honeybee and the mantis continued consuming the abdomen of the headless bee unimpeded, leaving only the wings and most distal part of the body, including the still pulsating stinger to fall to the ground. This initial encounter was over in a few minutes and after a brief face cleaning, the mantis once again assumed a stalking position. As honeybees continued to visit the citrus flowers, the mantis went on to successfully prey until no fewer than five honeybees met their fate. The honeybees appeared to grow increasingly wary of the flowers over time and would hover just short of landing. Eventually they stopped visiting this tree and its

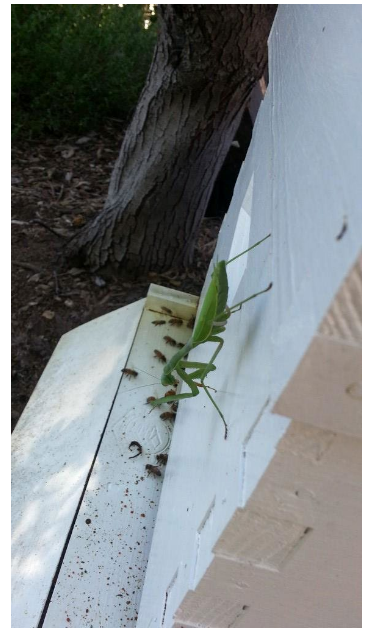


Figure 15: Mantis stalking beehive entrance. Photo credit: C. Tankersley.

Figure 16: Young mantis on citrus. Photo credit: C. Tankersley.

flowers altogether, which may be the result of a specific alarm pheromone secreted on the flowers from the attacked honeybee as warning to other honeybees. (Zhengwei 2019) The mantis eventually crawled down and away and disappeared temporarily only to be found hanging on the side of house under a lamp apparently to ambush the next unsuspecting meal.

While mantises can prey on insect pests, they are considered generalist feeders and are indiscriminate in the prey they will catch and eat, thus they are not deemed true beneficial insects. In fact, there are numerous examples of mantises catching and feeding on small birds, especially hummingbirds. Young juvenile mantises are very small and will feed on small insects like aphids, but they will quickly mature and require more substantial prey that may include beneficial insects and even their own species. On occasion adult mantises could be found stalking the entrance to the beehive looking for an easy meal. Still, despite their feeding proclivities, they are intriguing insects to observe and certainly enhance the diversity of the garden. The few honeybees lost during this predation resulted in no actual impact on the colony overall.

Chapter 2 – Ladybird Beetle and Aphid

The next two garden characters are very well known to gardeners. One is typically despised while the other is often cherished and revered; they are the aphid and the lady beetle, also known as the 'ladybug'.


Figure 17: Aphids on Golden. Photo credit: MJ Hatfield; Bugguide.net.

In the order Hemiptera, aphids are members of a very successful and enormously diverse group of insects. This large order that are often referred to as 'true bugs' includes bed bugs, cicadas, various hoppers, scale, leaf and stink bugs, whiteflies, and water bugs. (Triplehorn and Johnson 2004) While known for the variety of different and complex mouth parts, most true bugs like aphids have piercing-sucking mouth parts with special stylets enclosed in a thin sheath allowing the aphid to easily feed on plant sap. (Gullan and Cranston, 2014) Other true bugs like assassin bugs (Family: Reduviidae) have mouthparts adapted to feed on other insects and are considered beneficial insects. Still, other members of this diverse order have mouth parts specially designed to feed on blood, such as bed bugs, kissing bugs, and conenose bugs. (Gullan and Cranston, 2014)

There are an estimated 4,000 species of true bugs worldwide with most found in temperate climates. (NMNH 170) Aphids are a soft-bodies species without clear fossil records, but scientists believe they have lived on earth for over 280 million years. (Capinera 2006) During this time, they and their relatives successfully evolved unique strategies of reproduction and mutualistic and symbiotic relationships with other organisms. One of the most frustrating aspects of dealing with aphids as a gardener is the fact that aphid populations can grow very quickly.

This is because aphids can employ different methods of reproduction depending on the environment and food supply. One form is through sexual reproduction between male and female aphids with eggs laid to overwinter and hatch the following spring. (Flint and Karlik 2019) The other is through parthenogenetic reproduction (asexual reproduction without males), where adult females give birth to live offspring. This process is known as viviparity with the nymphs born as first instar female nymphs that are clonal (identical genetically) to the female parent. (Gulland and Cranston, 2014) By using this form of reproduction, female aphids can produce as many as a hundred offspring in a week. With warm and humid weather, the offspring can rapidly develop from nymph to reproducing adults in about a week. Aphids are generally wingless; however, based on environmental signals, competitive pressures between aphids, or dwindling plant resources, winged variations of mature aphids can develop that permit migration to alternate host plants. These adaptive qualities have allowed aphids to thrive while exploiting a wide variety of plants.

Figure 18: Aphids on rose buds. Photo credit: N. Laws; Pinterest.com.

While some plants can tolerate a minor infestation of aphids and may show little to no noticeable effects, other plants can be very sensitive to aphid feeding and develop twisted, curled, and discolored leaves and stems. Some plants react to aphid feeding by developing unique galls that are a swelling deformity in plants induced by chemicals injected during insect feeding.

Damage is also not restricted to direct feeding. Aphids are known to transmit, or vector many plant bacteria and viruses, which can prove to be more difficult to control than the aphids

themselves. The waste secretions from aphids also called honeydew is another issue as it attracts ants that feed on the honeydew and protect the aphids. The honeydew is also a perfect medium from which fungal diseases like Powdery Mildew and Black Sooty Molds can quickly develop further impacting plant growth.

There are many non-pesticide solutions to help control aphid infestations from physical removal insecticidal soaps. Still, no control method is more satisfying that observing predators feeding on aphids. There are many natural predators of aphids that include the Green Lacewing (*Chrysoperla rufilabris*), Minute Pirate Bug (*Orius insidiosus*), Assassin Bugs (*Zelus renardii*), and even parasitoid wasps such as *Aphidius ervi*. (Hajek 2004)

The well-known generalist predator in our story has a well-deserved reputation as a voracious feeder of aphids, the lady beetle. Lady beetles are in the order Coleptera and family Coccinellidae. There are over 5,000 species worldwide and while most are predators of soft bodied insects, some Coccinellids are considered agricultural pests, including the squash beetle (*Epilachna* borealis) and Mexican bean beetle (*Epilachna varivestis*). (Palli 2019) Some species of lady beetles such as the Harlequin ladybird (*Harmonia axyridis*) were specifically introduced from Asia to help control aphids but have since become a pest themselves by outcompeting many native lady beetle species. The Harlequin ladybird can also bite and cause an allergic reaction in sensitive people.

The characteristic lady beetle with its convex, dark spot covered, oval shaped body comes in various colors ranging from the typical red to yellow, orange, pink, gray and even black. The bright distinctive coloration is known as aposematism, which provides a warning to would-be predators that the insect is likely toxic or foul tasting and, indeed, ladybird beetles can secrete a

foul tasting chemical when roughly handled. (Palli 2019) Adult female lady beetles will lay clusters of small, yellow, oval eggs near colonies of aphids or other soft-bodied insects that hatch in about 3 to 10 days depending on temperature. While adult lady beetles can feed upon over a hundred aphids per day, newly emerged larvae have voracious appetites and can consume more than adults making this species a highly effective natural enemy (Hajek 2004). Larvae will molt four times over a period of about a month before affixing themselves to a solid surface and entering the pupal stage lasting a few weeks before adult emergence to start the cycle again.

The Interaction

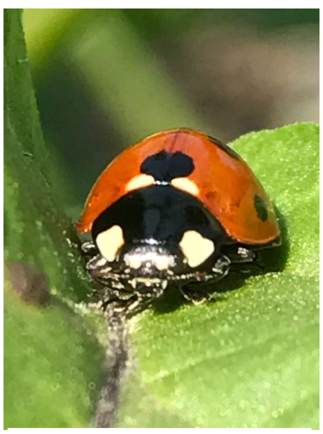


Figure 19: Convergent lady beetle (adult). Photo credit: C. Tankersley.

Shrub roses are strategically interspersed in the garden. Most were specifically chosen for their incredible fragrance and colorful globular blossoms with dense cupped petals. The fragrance of one golden-yellow rose near the house was noteworthy for its heady smells of citrus and tea. One day aphids appeared on the new buds and supporting stems of this favorite rose. The aphid species was identified as *Macrosiphum rosae*, aptly named the rose aphid. The population was very small with a few adults and about a dozen juveniles, so I intentionally let them be with the hope that beneficial insects may also find them. I became more concerned over time as predators did not arrive and the aphid population increased quickly causing feeding damage to the newly forming rose buds. Immediate intervention was necessary, thus I decided to use a special ‘bug blast’ water nozzle especially designed to kill soft-bodies insects. This classic cultural control method was effective for a short time, but the aphid

population quickly recovered. Fortunately, a beneficial insect arrived providing some assistance and was identified as the convergent lady beetle (*Hippodamia convergens*).

The single lady beetle seemed to prefer feeding on the younger nymphs over the adult aphids with distinctive large dark brown bodies with long antennae and cornicle tubes projections on the body. The lady beetle moved rapidly among the aphids and once one was selected, the lady beetle appeared to practically suck the aphid into its mouthparts and begin chewing on the still live aphid until it was gone. The lady beetle would then quickly clean its mouth parts and antennae before moving on to the next meal.

Another lady beetle soon arrived, and the pair fed readily on the aphids for a few days before disappearing. The aphid population had been greatly reduced and to my great excitement, several tightly grouped cone-shaped eggs had been deposited clusters near the remaining aphids. After four days after being deposited, the eggs hatched and what emerged were creatures resembling small alligators with an elongated, segmented bodies that were pale gray to black in color and covered in short spikes, orange spots and six legs. The larval form is quite distinct from the adults. A larva moved rapidly around and through the group of aphids with little notice, then stopped at an individual nymph where it quickly grasped it using the front pair legs to pull it toward its mouth where the nymph was quickly eaten. This process continued over and over until dozens of aphids were consumed. The larvae grew quickly with a ready food supply and molted four times growing quickly. While the adult ladybird beetles disappeared, many of the larvae found their way to nearby plants and attached themselves as prepupa to begin

Figure 20: Convergent lady beetle (larvae). Photo credit: C. Mancilla; Flickr, UNL Dept. of Entomology.

the cycle again. The small number of remaining aphids were then easily controlled with soapy water and the tea rose quickly recovered to produce numerous new rose buds.

There are many approaches that can be taken to help control aphids in the garden. The direct methods of physical removal or use of insecticidal soap, or neem oil can be effective against aphids if used consistently, but other techniques like encouraging natural predators and discouraging migration of aphids into the garden can provide a long-term solution to control this vexing pest. Aphids are preferentially drawn to plants of high nitrogen content, thus use of sustained release fertilizers can help reduce this attraction source. Additionally, one can help entice lady beetles to the garden by planting companion plants like calendula, coreopsis, dill, marigold, sweet alyssum, and yarrow as they provide important sources of pollen for adult lady beetles. To see lady beetles in the garden can lift one's spirit and provides a sense of optimism and is often thought to be a sign of good luck.

Chapter 3 – Cotesia Wasp and Tobacco Hornworm

The insect world is an unforgiving, ruthless place with insects vying for resources of food and protection while trying to reproduce and avoid being eaten. The types of interdependency between insects and other species, including plants, viruses, fungi and bacteria, which formed over the millennia, are almost as diverse as the number of insect species on the planet.

Scientists have defined the main key relationships between insects and other organisms as commensalism, mutualism, and parasitism. (Triplehorn and Johnson 2004) Commensalism is a type of relationship where one species benefits with minimal to no impact on the other. An example would include an animal that uses a flying insect to move from one location to another.

Mutualism describes the relationship where both species benefit from the relationship or interaction. A fundamental example of a mutualistic relationship that has co-evolved over millions of years is that between bees and plants. This relationship involves the attraction of insects and other animals to pollen and nectar produced by plants that ultimately aids in the pollination and reproduction of plants. A third major type of relationship is parasitism where one species lives off another, the hose, often resulting in the death of the host. Many insects have developed highly complex and often exclusive parasitic relationships with other species.


Figure 21: Tobacco hornworm, larva. Photo credit: C. Tankersley.


Figure 22: Hawkmoth (adult). Photo credit: selfliberatingflickr; Flickr; UNL Dept. of Entomology.

That brings us to the next insect interaction in our story. One of the characters can be the source of significant frustration and for those gardeners who endeavor to grow their own tomatoes, they will immediately recognize the larvae of the tobacco hornworm larvae (*Manduca sexta*). The tobacco hornworm is often confused with its close relative the tomato hornworm (*M. quinquemaculata*), which has dark blue or black horns with green margins and v-shaped white stripes. (Byron and Gillett 2017) The tobacco hornworm has a distinctive red horn at the distal (rear) end of body and black margins on straight white stripes. (Byron and Gillett 2017) All hornworm larvae prefer feed upon plants in the Solanaceae family that includes the tomato, tomatillo, peppers, potato, eggplant, and tobacco. (Byron and Gillett 2017) This insect belongs to the order Lepidoptera and family Sphingidae and the adults are

commonly referred to as hummingbird, hawk or sphinx moths. (Byron and Gillett 2017) These large moths have a remarkable ability to hover like hummingbirds while they feed exclusively on the nectar of flowers or orchids using a very long proboscis. (Byron and Gillett 2017)

The larvae are notorious for being superbly camouflaged and difficult to locate especially in their early larval stages; however, they develop quickly and can grow to almost three inches in length and half an inch in diameter. At this stage, they will consume a vast amount of foliage and even fruit, which is often the only time when they can be located on the plant. A mature caterpillar will also leave large barrel-shaped dark frass (droppings) that can be easily identified on plant leaves and stems further revealing the location of the offending caterpillar.

Figure 23: Hornworm pupa. Photo credit: C. Tankersley.

There are several methods to control populations of these voracious caterpillars, the simplest being direct hand picking. A biological control specific to Lepidopteran larvae can be found by using the naturally occurring soil bacterium called *Bacillus thuringiensis* (often abbreviated as Bt). (Byron and Gillett 2017) This bacterium can be purchased as a ready-mixed spray and operates as a fatal endotoxin that once ingested paralyzes the digestive tract causing the caterpillar to stop feeding and eventually death. This control is generally more effective on early instar larvae. The ability to locate and physically remove hornworms can be very satisfying.

However, an equally satisfying method of natural control comes in the form of a natural enemy called the Cotesia wasp (*Cotesia congregata*). This endoparasitoid wasp is in the order Hymenoptera and family Braconidae. (Crockett et al 2014) This family includes an incredibly diverse and highly specialized group of insects that have evolved to complete at least part of their

lifecycles inside lepidopteran hosts. Many of these small wasps are very host specific and may only parasitize a single species of larval hosts. As a result, they have adapted many unique detection mechanisms to locate hosts based on plant and chemical cues released during larval feeding. However, the relationship between larvae and wasp is even more complex. Many of these wasps have a mutualistic symbiotic relationship with a polydnavirus that permits the wasp to evade the larvae host immune defenses that would normally be directed against a foreign object, such as the injected wasp eggs. (Byron and Gillett 2017) During the ovipositing process, the wasp will inject a very small amount of a polydnavirus and venom along with their eggs into the hemolymph of the larvae host. The venom temporarily paralyzes the host while the polydnavirus blunts the immune response against the deposited eggs and arrests further development of the host caterpillar. Genetic study has revealed that the polydnavirus genome is incorporated directly into the DNA of the parasitic wasp, thus is transmitted genetically from adult to offspring. (Strand and Burke 2015) When expressed in the host tissues, the virulent polydnavirus genes will effectively control larval host physiology, behavior, and immune responses to the benefit the developing wasp larvae. Many other wasps in the family Ichneumonidae also employ polydnaviruses during oviposition and many scientists have begun to reassess whether polydnaviruses may be a core component of the wasp genome instead of a distinct virus. (Strand and Burke 2015)

Interaction

The deposited eggs hatch in 1 to 3 days and the tiny, grub-like larvae spend the first two instars living within the host and feeding off the host tissues. After the second instar, the larvae cut small holes through the host cuticle to complete the third instar outside but affixed to the host

before spinning white cocoons where they pupate and develop into adults. (Byron and Gillett 2017)The tobacco hornworm has a very short life cycle developing from egg to a mature adult caterpillar in about 20 days. The adult moths only lay a few eggs per plant to reduce competition and help ensure survival of their young but left unchecked just a few caterpillars will completely defoliate an entire mature tomato plant and even fruit. I have never directly observed a Cotesia wasp on or near the tomato plants, but I know these small, rapidly moving wasps of about an 1/8 of an inch long, with black with yellow legs are very difficult to observe. Still, I know at least one female wasp had located a hornworm and successfully oviposited her eggs, because a tobacco hornworm covered in numerous individual cocoons was discovered in the dense foliage of a tomato plant in the garden. The most likely endoparasite is the wasp commonly found in Southern California, *C. congregata.*

Figure 24: *C. congregata* pupae on *M. sexta* larvae. Photo credit: R.J. Reynolds Co.; Bugwood.org.

It would have been fascinating to observe the moment when the wasp larvae emerged from the hornworm to create their characteristic ovoid white cocoons as this would have been something out of a science fiction movie. It was clear that the baby wasps had already emerged and flown away as there were small holes at the tip of each of the approximately hundred cocoons from which the small wasps had exited. The lifecycle from oviposition to emergence of adult wasps takes approximately 1 to 2 weeks.

While not a witness to the entire process, I was pleased that the garden was host to this incredible duo of predators and prey and continue to be amazed at the complex behavior and

biology underlying these insects. If you ever observe a hornworm covered in numerous silken white cocoons, resist the temptation to destroy it, but instead allow the wasp larvae to develop and emerge, to begin the next generation of natural hornworm control.

Chapter 4 – Dragonfly and Mosquito

The next set of characters in our story includes one that could not be more detested and is the cause of significant human and animal illness and death – the mosquito. The other is an insect that is often revered and has been idolized for thousands of years being the subject of ancient mythology and cultural symbolism – the dragonfly.

Dragonflies are colorful winged insects in the order Odonata that translates as ‘toothed ones’ in Latin. (Dokkum 2015) They have a distinctive body structure consisting of three parts: the head with a pair of multifaceted, compound eyes, the thorax attached to which are two pairs of broad, transparent wings and three pairs of powerful, barbed legs ending in sharp hooks, and an elongated abdomen. There are an estimated 5,000 species of dragonfly in the world and appear in a dazzling variety of colors and sizes ranging from about half an inch to over 6 inches long. (Zielinski 2011) Damselflies are another flying insect in the order Odonata, but in a different suborder and are often confused with dragonflies as they have a similar overall body shape. However, there are a few key differences, such as a generally slimmer body size and resting position of the wings that are held folded straight along the abdomen unlike dragonflies that hold their wings spread perpendicular to their body.

Interestingly, one of the largest insects found in the fossil record includes an extinct ancestor of the modern dragonfly in the order Meganisoptera. These insects, often referred to as

Griffinflies, lived during the Palaeozoic period about 300 million years ago and had wingspans of about two feet. (Dokkum 2015) Dragonflies, like most other terrestrial insects absorb oxygen directly into the body through tiny holes in the abdomen called spiracles. It is hypothesized that the ancient dragonfly species were able to grow to such immense size due to high relative oxygen levels present during this period compared to present day. (Zielinski 2011)

Dragonflies are insectivores and will generally only eat insects they can catch in the air. It may be surprising to know that their larval stage has an equally voracious appetite for prey, although this lifecycle is exclusively aquatic. Dragonflies undergo incomplete metamorphosis, which means that the adults will lay eggs that hatch into nymphs and here is no pupal stage. (Triplehorn and Johnson 2004) Nymphs will molt

Figure 25: *Libellula saturata* (nymph). Photo credit: B. Barber; Bugguide.net.

multiple times underwater depending on the species. The overall length of the nymphal lifecycle is highly variable depending on species and can last months to years, with the insect living an exclusively aquatic life during this period. Nymphs will emerge from the water crawling up stems of plants and undergo a final molt to become adults. Nymphs bear no resemblance to the adult form. In fact, nymphs are often a drab brown or gray color with six clawed legs, large eyes and a strong, extendable lower jaw that can quickly catch other aquatic invertebrates such as larval mosquitos, tadpoles, crayfish, and small fish.

Adult dragonflies have prominent compound eyes that take up most of the space on their heads. The dragonfly can accurately detect and track very small movements against a moving background across 360 degrees and can distinguish between different color wavelengths and

polarization. (WelcomeWildlife.com) Each compound eye is composed of thousands of hexagonal facets called ommatidia that respond in sequence to movement. Between the eyes lies another important organ called the ocelli that is thought to help dragonflies maintain stable flight. Like the eyes, the dragonfly wing structure and flight muscles are also remarkable and give the dragonfly an unparalleled flight capability. Dragonflies can hover in place, fly forward, backwards, and upside down, and achieve speeds up to 30 miles an hour. (Dokkum 2015) While adult dragonflies are opportunistic feeders generally eating whatever they can catch and hold, they are well known for their ability to control large mosquito populations, with a single dragonfly capable of consuming hundreds of mosquitos per day.

The mosquito, in stark contrast, is at best an annoyance but at worst can cause significant harm. Whether it is the occasional bite and the subsequent itchy welt or just the incessant buzzing that can envelop you when outside, most people just strive to endure mosquitos during the warm summer months. However, perhaps no insect has been as powerful force on human history as the mosquito. The mosquito is said to have contributed to the fall of the Roman Empire, prolongation of the United States (US) Civil War, and were intentionally exploited as a biological weapon during the Second World War. (Winegard 2009)

The mosquito is in the order Diptera and the family Culicidae. There are an estimated 3,500 species of mosquito worldwide. (CDC 2020) However, only about 200 species are currently found in the US, with about 12 known to transmit or act as vector for disease. (CDC 2020) Globally, over a million people die every year due to mosquito-borne diseases, making mosquitos indirectly one of the deadliest animals on

Figure 26: *Culex tarsalis* (adult). Photo credit: PJ Bryant; acvsd.org.

earth. (CDC 2020) Malaria is the most well-known mosquito-borne disease, which is caused by a *Plasmodium* parasite. (DHHS 2020) This unicellular eukaryote parasite requires both the mosquito (*Anopheles* sp.) and human host in order to complete its lifecycle. (DHHS 2020) Malaria is relatively uncommon in the US, with most reported cases tied travel and immigration. The leading cause of mosquito-borne disease in the US is West Nile virus (WNV), which is transmitted primarily the mosquito *Culex tarsalis*. (DHHS 2020) Only about 20 percent of people will develop symptoms, and about one percent of infected individuals can develop serious or fatal illness. (DHHS 2020) Other mosquito species present in the US are known vectors of disease and include species of *Sp. Aedes*, which can transmit diseases of dengue fever, yellow fever, the Zika virus, and a relatively new virus in the US called chikungunya that can cause debilitating fever, headache, and muscle and joint pain. (DHHS 2020) Pets and livestock are also susceptible to mosquito born illness. The mosquito *Aedes sierrensis* is the primary vector of dog heartworm and the *Culex* species of mosquito are vectors for the serious Eastern Equine Encephalitis. (DHHS 2020) Given the potential serious consequences from a mosquito bite, everyone should appreciate observing mother nature imposing some natural suppression on mosquito populations.

Like dragonflies, mosquitos have compound eyes that are superior at detecting movement, but they can also see objects that are not moving. Mosquitos rely on specialized chemo sensors to detect a potential vertebrate blood meal. Mosquitos are very sensitive to levels of carbon dioxide (CO_2), a gas released as by-product of respiration, but are also skilled at detecting specific skin odors, sweat and body heat. (Winegard 2009) Using specialized sensors, the female mosquito uses the CO_2 concentration gradient in the air as a type of homing beacon to help orient

their flight direction toward the source of the CO_2. Once near the animal, the female mosquito will use visual cues to guide her toward a potential blood meal. (Winegard 2009)

While male mosquitos feed exclusively on plant nectar and sap, female mosquitos require a blood meal to provide the necessary iron to support successful egg development and reproduction. When a female mosquito bites, it secretes a small amount of saliva containing both an anesthetic and anticoagulant to help her discreetly and quickly draw up as much as over three times her body weight in blood before flying away.

Mosquitos undergo complete metamorphosis with distinct egg, larva, pupa, and adult stages. Eggs are laid on the water surface of a pond, lake, or even small pool in a leaf. They are laid either singly or in groups called rafts depending on the species and hatch generally in less than 48 hours. (US EPA 2017) Most species of mosquito larvae use a siphon extended above the water surface in which to breath, while others lay close to the water surface to take in oxygen via special openings. Larvae, also called wigglers and will feed on organic matter and microorganisms in the water. After molting four times, they enter a non-feeding pupa stage and are generally referred to as tumblers due to their motion in the water when disturbed. (US EPA 2017) At the end of end of the pupal stage an adult mosquito will emerges from the pupal case and rest at the water surface to allow their wings to expand and fully dry before taking to the air to begin the cycle again. The overall development time from egg to adult is highly dependent upon temperature and species taking as short as four days to up to a month. (US EPA 2017)

The Interaction

The interaction of dragonfly and mosquito centered around the prominent waterfall and pond located in the middle of the garden. The pond is a frequent stopping point for a variety of insect

species, including many dragonflies and damselflies. While at least three different species of dragonfly have been observed in the garden, one particular species that seemed to make regular appearances was a brilliantly colored species called the Flame Skimmer (*Libellula saturata*). The males are large with, bright orange bodies and semitransparent wings that shift from orange to clear and amber at the wing tips. The females are slightly smaller with wings that are almost clear in comparison to the male. Two other dragonfly species that also occasionally visited the pond are the Blue-eyed Darner (*Rhionaeschna mutlicolor*) and the Common Green Darner (*Anax junius*). Male dragonflies are highly territorial, a trait regularly demonstrated by the male Flame Skimmer. One male would regularly patrol the region around the pond and aggressively chase off other dragonflies that ventured into the garden. This Flame Skimmer would often approach other flying insects in midair to investigate but most often would move away to resume patrols or land on a nearby tree branch. The dragonfly would even occasionally approach small birds, including hummingbirds in flight as an apparent show of his dominance. The Flame Skimmer followed a routine clockwise flight pattern around the pond and garden, consistently landing at the same tree branch overlooking and in clear view of the pond.


Figure 27: Flame Skimmer (male). Photo credit: C. Tankersley.

The garden at dusk is different than during the heat of the day and takes on a soothing, peaceful quality; however, this peace was on occasion spoiled by the untimely appearance of mosquitos that would descend to ruin the mood and chase us inside the house. One day, the Flame Skimmer was on the hunt and literally seized mosquitos out of the air directly in front of

us. This sight repeated numerous times over a period of days, with other dragonflies occasionally joining the foray to create an almost swarm-like group in an almost choreographed synchronized zig zag patterns spanning the garden. It was clear that what was being witnessed was a truly special sight. Then almost as quickly as it began, the dragonflies disappeared, and the mosquito problem appeared to be resolved.

Figure 28: Flame Skimmer (female) depositing eggs in the pond. Photo credit: C. Tankersley.

Ponds can be rewarding additions to any garden and will quickly become important habitats for many animals and insects, including dragonflies. However, they do require some regular maintenance. The water level should be regularly checked, and water and de-chlorinator added as needed. Debris and dead or decomposing plants should also be removed as it will significantly reduce of oxygen levels of the water. As discussed previously, the eggs deposited by adult dragonflies in mid to late summer will hatch to become nymphs that can live for many months at the bottom of the pond. Thus, as part of performing pond cleanup, muck and debris removed from the pond should be placed outside the pond in a location where any nymphs that were inadvertently removed can find their way back into the water. Optionally, they can be picked up by hand and returned them to the water, but one should be careful as nymphs can bite.

Chapter 5 – Common Green Lacewing and Spider Mites

Lacewings are in the order Neuroptera, which means 'sinew-winged' or 'net-veined' describing the highly veined, large membranous wings found on the adults. This order consists of over 5,000 species worldwide and about 285 in the US and include antlions, mantisflies, owlflies, (Meyer 2020) Within this order is the family Chrysopidae in which lacewings are classifiedMost Neuropterans are predaceous of other insects, thus considered beneficial insects, yet they often go unnoticed in the garden as they live nocturnal existences. The insects in this order occupy mainly terrestrial habitats but some species are aquatic; all undergo complete metamorphosis. (Triplehorn and Johnson 2004)

Figure 29: Green lacewing, adult. Photo credit: B. Valentine; UNL Dept. of Entomology.

Adult lacewings are poor flyers and are typically more active at dusk. Since they are often attracted to outside lighting, this can provide an opportunity to view these rarely seen, delicate and beneficial insects. The adult common green lacewing (*Chrysoperla carnea*) is about ¾ of inch long with a light green body and a pair of large wings folded in a tent-like manner over its abdomen. (Bessin 2019) Adults have a pair of long, slender antennae and distinctive golden color eyes. Adult lacewings can produce a defensive, foul smelling secretion that is used as deterrent against predation by ants.

The delicate form of the adult green lacewing is in sharp contrast with that of its larval stage. While adults mainly feed upon nectar, honeydew, and pollen, the larvae are voracious, generalist predators feeding upon soft-bodied insects such as aphids, mealybugs, thrips, spider mites,

whiteflies, and leafhoppers. (UC IPM 2014) The green lacewing undergoes complete metamorphosis with distinct egg, larva, pupa, and adult stages. (UC IPM 2014) Often in the evening, the female will lay a few dozen small, oblong shaped eggs deposited in small groups elevated at the end of hair-like filaments above the plant surface to reduce prevent predation by hatching lacewing larvae. (Bessin 2019; Hajek 2004) The larvae hatch in about 3 to 10 days depending upon temperature and humidity and will quickly grow to about 3/8 inch long. (UC IPM 2014) They resemble small alligators with spiky appendages and have eight legs and prominent, sickle-shaped hollow jaws from which they will grasp, inject a paralyzing venom, then suck out the body fluids of the prey. (Bessin 2019) Feeding upon a wide range of insects of all stages, larvae will roam plant foliage in search of prey. Green lacewing larvae can be referred to as garbage or junk bugs, since like many other insects, they will often affix debris and the dead, exoskeletons of former prey to their bodies as a type of camouflage to protect against predation.

Figure 30: Lacewing eggs. Photo credit. R. Bessin; UK Entomology.

Figure 31: *Chrysopidae* sp. with affixed prey exoskeletons. Photo credit: J. Gallagher; Flickr, CC BBY 2.0.

The pest character in this chapter is not an insect, but a member of the spider family (phylum: Arthropoda, order: Trombidiformes; family: Tetranychidae). It is the two-spotted spider mite (*Tetranychus urticae*), which is an abundant pest of many different species of deciduous ornamental and vegetable plants. The adult two-spotted spider mite is almost microscopic in size (about 0.02 inches in length) and under optimal conditions of low humidity and high temperature can have short development lifecycles lasting about a week or less. (Fasulo and Denmark 2009) This often results in a rapidly growing population of overlapping generations and can make identification and control of spider mites extremely challenging. Adults have two body segments and four pairs of legs, with two dark spots on the front body segment. The adult coloration can be variable from brownish, orange-red to light yellow, or green. Females spider mites lay very small translucent, spherical eggs that hatch after a few days into colorless larvae with six legs about the same size as the eggs. (Fasulo and Denmark 2009) What follows are two nymphal stages called the protonymph and deutonymph, with nymphs having only four pairs of prolegs before finally achieving the adult form. (Fasulo and Denmark 2009)


Figure 32: Two-spotted spider mites. Photo credit: University of Florida, IFAS.

Spider mites have piercing-sucking mouthparts that will puncture a single plant cell at a time to suck the sap. The feeding subsequently produces a stippling effect on leaves that resembles a pattern of small light-colored dots, eventually progressing until the leaves yellow and die. (Fasulo and Denmark 2009)

Figure 33: Stippling damage from thrips on oak. Photo credit: T. Tigner; Bugwood.org.

Another characteristic of the two-spotted spider mite are the fine strands of silken web that are often spun by mites across the plant branches and underside of leaves. This is thought to provide protection for the eggs and nymphs and may permit the mites to easily move from one part of the plant to another as they feed. The mass feeding of spider mites can quickly overwhelm plants and significantly reduce a plant's photosynthesis capacity resulting in stunting and death. Spider mites prefer the hot, dry conditions of the summer months and plants that are drought stressed are often targeted.

Identification of this pest is key to its management, since spider mites damage can easily be confused with damage by other pests such as leafhoppers and thrips that feed in similar fashion and cause similar damage. An effective way to sample and help identify the species is to sharply tap the foliage with the offending insects over a sheet of white paper. The insects will drop onto the paper where careful examination with a magnifying or hand lens can aid in their identification. Spider mites are small, slow moving translucent to light yellow-orange insects with two darks spots on each side of the body.

The Interaction

All the plants in the garden are appreciated, but one of the favorites include the salvias. This member of the mint family comes in many different shapes, flower structures, colors, and fragrances. They are also highly attractive to hummingbirds and insects, including bees,

Figure 34: Chiapas Sage. Photo credit: C. Tankersley.

butterflies, and moths. One noteworthy variety is *Salvia chiapensis* also known as Chiapas Sage, so named for its native region in Chiapas, Mexico. This drought tolerant and wonderfully scented plant displays groups of brilliant, pink to magenta-colored flowers arranged in whorls widely spaced along the plant stems. This mostly herbaceous and tender plant has broad, deeply veined leaves and the flowers that bloom during hot weather are favored by many species of hummingbirds. The hot, dry summer months also provide the best development conditions for the two-spotted spider mite that quickly infest the same salvias and azaleas year after year. As a result of this recurring pest issue, I decided to supplement the usual control methods and purchase what is considered one of the best multi-purpose predators for the garden, the green lacewing.

The lacewing adults and larvae arrived at my doorstep via courier in separate plastic containers. Following the instructions, I misted each of the plants with a light covering of water, then gently emptied the contents of the bottle containing the larvae onto the salvia and azalea plants. I then opened the plastic cup containing numerous light green lacewing adults near the salvia plant and allowed the insects to disperse on their own. The plan was for the larvae to provide some immediate control of the spider mites, while the adults may establish a persistent population in the garden and provide long-term control of not only spider mites but other pests in the garden.

I waited about 30 minutes before returning to the salvia bush and using my 10-power hand lens began examining the underside of the leaves for predation activity. I was not disappointed and even without the lens, I was able to observe several fat-bodied lacewing larvae with prey locked in their characteristic sickle-shaped jaws and other larvae moving about on the salvia foliage in an almost erratic manner in search of prey. The hollow mandibles of the lacewing larvae will first pierce the prey, then salivary enzymes injected into the prey will breakdown tissues that can easily be sucked out. The dead hollow bodies of spider mites littered the salvia foliage. There was only a minimal amount of fine webbing from the spider mites that extended from the upper part of the plant across the salvia, thus I was able to visually inspect most of the plant. As the lacewing larvae fed, it appeared that other spider mites slowly gathered in a tighter group, which may have been an aggregation strategy to improve survival following predatory cues. The new method of pest control proved to be very successful and over time adult green lacewings appeared to be common visitors to the garden.

Many pests like spider mites can be inadvertently introduced to the garden from purchased plants, thus careful examination of plants and prompt treatment, if needed, is key to reduce or prevent infestations. Pesticide use should be carefully evaluated and implemented only as needed to control severe infestations. The type of pesticide and method of application should be considered to help ensure maximum success against the specific pest while minimizing impacts to natural predators. Many species of spider mites are known to now be resistant to pesticides, thus other control measures are highly advisable. Insecticidal soap or neem oil can be effective at controlling spider mite populations. Several other commercially available natural predators of spider mites are available, and many are used routinely in commercial greenhouse

applications. These include the predatory mites *Phytoseiulus persimilis* and *Mesoseiulus longipes*, and the larvae from a small gall midge called *Feltiella acarisuga* that will prey on adult, larva, and eggs of the two-spotted spider mite. (Hajek 2004)

The use of cover crops and companion planting are effective ways to attract natural enemies and pollinators to the garden. While the larvae of many beneficial insects are insectivores, the adults often require nectar and pollen sources to survive and reproduce, thus without these foods, many beneficial insects will not remain in an area long term. Fragrant herbs are very attractive to beneficial insects like the adult lacewing. Other companion plants include bachelor button, chamomile, chives, coriander, dill, parsley, sweet alyssum, wild celery, and yarrow. (Bugg et al. 2008)

Cover crops like fava beans, radish, and vetch can serve a dual purpose, providing pollen and nectar for beneficial insects but also serve to improve soil quality by loosening hard, compact soils and improve water and nutrient retention. Many cover crops can also support nitrogen fixation in the soil and increase organic matter. In turn this provides support to mycorrhizae activity, which are a key group of symbiotic fungi that along with the many soil dwelling insects, such as mites and springtails are essential for the proper functioning of the soil microbiome and plant health. Another beneficial insect that relies on cover crops for sources of flower nectar and pollen will be the subject of the next chapter.

Chapter 6 – Hoverfly and thrips

The final beneficial insect in our story is the hoverfly also recognized as a flower fly. This unique insect is in the Order Diptera and family Syrphidae, hence it is also known as the syrphid fly. There are over 6,000 known species of hoverfly worldwide. (Thompson 1999) Many adult hoverflies use a clever technique of Batesian mimicry with bright coloration and distinct bands on the abdomen that resemble coloration of bees or wasps that may dissuade would-be predators. (Bugg et al. 2008) However, hoverflies do not have stingers and unlike bees with two pair of wings, hoverflies only have one pair that are held out from the body at about a 45-degree angle. Hoverflies have rounded heads with prominent compound eyes and short antennae that are distinct characteristic of dipterans. Wasps also have long antennae and narrow eyes on a triangular shaped head, while bees generally have elbowed antennae. The behavior of adult hoverflies is also distinct to that of bees. Bees move methodically and slowly from flower to flower while hoverflies are more erratic and often hover in place and can fly backwards, which is a not a behavior observed in hymenopterans. Many hoverfly species are considered beneficial insects not only because adults are key pollinators for various species of flowers, but the larvae are important predators of aphids and other soft-bodied pest species such as caterpillars, scales, whiteflies, and thrips. (Laubertie et al. 2016)

Figure 35: *Syrphidae* sp (adult). Photo credit: M. Johnson; Flickr; UNL Dept. of Entomology.

The hoverfly undergoes complete metamorphosis with distinct egg, larval (also called a maggot), pupal, and adult stages. Eggs are a creamy white color and about the size and shape of a grain of rice and are generally laid singly and hatch in about 4 to 8 days depending on species and temperature and season. (Bugg et al 2008) Hoverfly larvae have variable appearance and habitat depending on the species. The larvae of some species are known to occupy the nests of ants, termites, or bees in a commensalism relationship with the hoverfly larvae adopting the odors of their hosts and will prey on host larvae. (Gullan and Cranston 2014) Other syrphid larvae live on decaying vegetation while others such as the larvae of the drone fly (*Eristalis tenax*) that live in polluted aquatic environments and have long breathing tubes that extend to the water surface like a snorkel. (Gullan and Cranston 2014)

Figure 36: *Syrphidae* sp hoverfly maggot preying on aphids. Photo credit: Steve&Alison1; Flickr; UNL Dept. of Entomology.

The predatory hoverfly larvae usually have a smooth, maggot-like appearance with gray-green coloration and narrow white stripes on the body. They do not have legs and rely on the female hoverfly to deposit the eggs in reasonable proximity to prey. Although they do not have eyes, they can still effectively move about using an undulating motion to navigate across vegetation randomly in search of prey. Larvae will proceed through three or more instars over several weeks, growing quickly to about half an inch in length. (Bugg et al 2008) During this period, the larvae can consume a significant number of soft-bodied pests, especially aphids. The maggots will then attach themselves to a stem or a leaf and enter the pupal stage. The duration of

the pupal stage is highly variable depending on temperature and season and can take about a week during summer months and many weeks during the winter. In severe winter climates, pupa will overwinter in the soil or under heavy mulch or leaves. (Bugg et al 2008)

The pest species in this chapter are thrips, which may not be that well known but can cause significant damage to vegetable and ornamental plants especially those grown commercially in greenhouses. Thrips belong to the Order Thysanoptera, so named for the fringe of long hairs on the wings of the adult insects (the Greek word thysanos means fringe and ptera means wings). Thrips are very small (generally 0.02 to 0.2 inches long), slender bodied insects with most possessing narrow wings that are covered with a dense fringe of hairs. Another unique characteristic of adult thrips is their asymmetrical mouthparts such that they only have a single left mandible.

There are over 5,500 described species of thrips worldwide and about 700 described species in North America. (Capinera 2006) Many species of thrips have been accidently introduced into the US via horticultural trade involving transport of plants, flowers, fruits, and vegetables by air from all over the world. Two commonly found introduced species in California that cause significant damage to commercial crops are the greenhouse thrips (*Heliothrips haemorrhoidalis*) from Brazil and myoporum thrips (*Klambothrips myopori*) from New Zealand. (Driesche and Hoddle 2020) While some species of thrips are predatory and others feed on soil fungi, most are considered pests and feed on plants using specialized needle-like stylets in the mouth to puncture individual plant cells and suck out the contents.

Both adult and immature thrips will feed on plants causing stippling and silvery streaks on the plant surfaces as the individual plant cells die. Specks of dark fecal droppings present on

plant leaves will also be evidence of the thrips presence. Plants can often tolerate some feeding, but severe infestations of thrips can greatly reduce the photosynthetic ability of plants causing stunting and poor fruit set, and cosmetic damage to vegetables and flowers. One of the most significant impacts of feeding by thrips can be scarring to fruits and vegetables leading to spoilage and waste. (Driesche and Hoddle 2020) This also applies to the damage and distortion caused to buds and flowers of ornamental plants, which are particularly alluring to thrips. In addition to damage caused by direct feeding, many species of thrips are also known to transmit plant viruses including tospoviruses that can affect a variety of ornamental and vegetable plants causing considerable damage. (Driesche and Hoddle 2020)

Thrips undergo incomplete metamorphosis, with five stages of development, including egg, larvae (referred to as nymph), prepupa, pupa, and adult. (Bethke et al. 2014) The prepupa and pupa stages are not true pupal stages like other insects where there is an internal transformation of tissues. Instead, prepupa and pupa stages resemble the adult form but with immature wing buds. (Bethke et al. 2014) These stages are also non-feeding or quiescent. The lifecycle for thrips also varies considerably depending on temperature and humidity, with development often pausing altogether at temperatures below 50°F. (Bethke et al. 2014) Female thrips lay kidney-shaped, whitish eggs in leaves, flower petals, fruits, and the soft parts of plant stems. First instar larva will emerge from eggs in about 2 to 4 days and immediately begin feeding. (Bethke et al. 2014) The first and second instars last about a week before entering the non-feeding prepupa and pupa stages that occurs within soil or ground litter. The last pupal stage lasts about 1 to 2 days as the wings fully develop. (Bethke et al. 2014) Adults then fly away to locate suitable food and the cycle begins again. Female thrips can lay hundreds of eggs in a

season, with a lifecycle taking as short as two weeks. (Bethke et al. 2014) As a result, populations of thrips can quickly reach infestation and damaging levels. The ability of this pest to quickly reach infestation levels is further enhanced such that some species of thrips demonstrate parthenogenesis, which is a form of asexual reproduction where females can lay viable eggs without being fertilized by males. (Gullan and Cranson 2014)

The Interaction

A species of thrips commonly observed in Southern California is the native western flower thrips (*Frankliniella occidentalis*), which is a common pest in the garden. (Bethke et al. 2014) It has a strong preference for the ornamental flowering plants such as the azaleas and many of the English roses. Feeding injury to the roses often occurred on the new rose buds of the season and resulted in discoloration and deformation of the buds that ultimately would fail to fully open, then wither and fall off. By the time the damage was observed it was often too late to salvage the rose buds. The thrips damage to the azaleas resulted in deformation, curling and cupping of the young leaf growth, which significantly reduced the attractiveness of the plant. While plants would ultimately recover over time and resume flowering later in the season, the damage was unsightly and likely resulted in some overall stunting and reduced plant vigor.

Figure 37: Western flower thrips (Adult-left, nymphs-right); Koppert Bio Sys; Flickr; UNL Dept of Entomology.

The common oblique syrphid hoverfly (*Allograpta obliqua*) was a dependable visitor and pollinator in the garden, but for many years I did not realize that it could also provide an

effective means of biological control for many common garden pests. I viewed it merely as one of the many pollinators attending to the flowers and did not connect its presence with the appearance of a few nondescript small white eggs the shape of grains of rice deposited within the foliage of one of the azalea shrubs. Initially, I could not identify the source of the eggs, thus was inclined to destroy them. However, curiosity led to careful observations over a period of days, after which a small, maggot-like creature about 1/8-inch in length appeared. It could have easily been confused with a small caterpillar, but upon close inspection it did not have legs. It had a wrinkled outer surface with small dark spots along parallel lines down the sides of the body. One end was pointy and the other flattened, but it was not possible to differentiate the anterior (front) from posterior (back) end. After some research, the odd creature was identified as a syrphid hoverfly larva. Attempts to observe the larva feeding on thrips was difficult during the daylight hours, and thrips are easily disturbed and will quickly jump and fly away. It has been reported that hoverfly larvae are more active in the evening but given their relatively small size they are quite difficult to see. I was not able to observe the hoverfly larva feeding on the thrips and after a few days, the larva seemed to disappear. Larvae of the hoverfly have been known to be parasitized by ichneumon wasps, but the fate of this hoverfly larva was never understood. Still, knowing that hoverfly eggs were deposited in the first place provided a sense of satisfaction that efforts at attracting various insects, good and bad, were successful. I am reminded by my initial inclination to remove the hoverfly eggs believing that they were from a pest. Likewise, the larvae could easily be mistaken for a small caterpillar, thus the importance of accurate insect identification before reacting should be emphasized. Since hoverfly larvae are very sensitive to chemical controls including insecticidal soaps, caution should be used when larvae are present.

Control of thrips is very difficult for several reasons. They quickly disperse when disturbed and are often concealed within plant foliage where they can be shielded from chemical controls. Cultural control measures that have proven effective in commercial settings, include crop rotation, control of weeds, and mowing tall grasses that can be overwintering sites for adult thrips. (Bethke et al. 2014) Eggs from thrips can overwinter in the potting soil of purchased plants, thus it is a good practice to purchase plants from reputable sources. Effective chemical controls include various Spinosad and pyrethroid formulations, but some species of thrips, especially the Western flower thrips, are known to be resistant making biological control efforts increasingly important, especially in greenhouse conditions. (Bethke et al. 2014) Other commercially available biological controls for thrips are predatory nematodes such as *Steinernema feltiae*, species of predatory mites, and even fungal pathogens. (Bethke et al. 2014; Driesche and Hoddle 2020)

Conclusion

The interaction of pests and predators presented in these chapters represents a focal and intimate view of a single urban garden but relates to a larger perspective for the critical roles of insects in an interconnected and healthy ecosystem. There is an old axiom that states one should think globally but act locally, which may be a bit cliché but is nevertheless essential and applicable to the home garden. Even small changes made across many small home gardens can collectively produce a profound and meaningful impact over the broader ecosystem. Indeed, the scale of the home

Figure 38: Monarch butterfly (*Danaus plexippus*) on Echinacea. Photo credit: C. Tankersley.

garden cannot be compared to modern agriculture, but many of the same natural pest control strategies being used in modern agricultural settings can be successfully applied to the home garden.

Farmers have known for many years that pests with high reproductive ability have a potential for high rates of genetic mutation giving pest populations to the ability to develop resistance to insecticides. By employing various control tactics that are carefully designed to enhance natural controls and disrupt critical steps in the pest life cycle, the pest population can often be faced with an overwhelming set of challenges that cannot be overcome. While complete elimination of a particular pest may be desirable, it is most often unachievable and unreasonable. Instead, a more balanced objective would be to suppress the pest population to a point necessary to prevent significant and permanent harm to plants.

A process or strategy that employs a combination of control methods with an emphasis on long-term pest prevention is referred to as Integrated Pest Management (IPM). A few simple IPM tactics can easily be applied in the home garden setting to provide enormous overall benefit in the long term. One of the first tactics and often the easiest to implement are collectively referred to as Cultural Controls, which refers to alterations that can be made to the environment and host plants to suppress or prevent pests. For example, by maintaining plant health through proper nutrition and growing conditions, plants are better able to withstand pest injury. Other examples of cultural control are crop rotation, removal of fallen fruit and crop residues, and the suppression of weeds that can function as reservoirs for

Figure 39: Hive and flowering peach. Photo credit: C. Tankersley.

insect pests where they can develop before moving into specific crops. Intercropping plants is another effective technique where plants that are more desirable than the main crop are grown nearby. The trap crop acts to divert pests away from the primary plant or crop, which can then be removed and destroyed.

Another IPM tactic involves use of Biological Controls that entails the purposeful manipulation and use of beneficial organisms (also called natural enemies) to control pest populations. (Hajek 2004) As previously described, natural enemies employ numerous behavioral and biological strategies with respect to their host or prey. Some function as parasitoids where the immature stages live within the host resulting in its death following emergence of the adult stage. Other species function in a parasitic manner and generally live their entire lifecycles within the host, such as parasitic nematodes. While many parasitic natural enemies kill the host directly, others only reduce the total reproductive ability of the host without resulting in its death. (Hajek 2004) Many of the insectivores highlighted previously directly prey and feed upon pests. Biological control tactics are further divided into three types that include classical, augmentative, or conservation. (Hajek 2004)

Classical biological control involves the use of imported, non-native natural enemies to control an introduced or non-native pest species. Prior to introduction there is extensive evaluation of the non-native species to evaluate its effectiveness, potential off-target effects, and integration into a habitat. (Hajek 2004) Augmentative biological control refers to use of commercially reared natural enemies that can be released to quickly reduce a pest population and is often employed in commercial greenhouse settings. (Hajek 2004) Finally, conservation biological control measures involve creating a more hospitable environment to attract and sustain

populations of natural enemies. (Hajek 2004) Many examples of conservation control were examined in previous chapters. Methods include planting companion flowering plants and establishing overwintering habitats for natural enemies. The targeted use of naturally occurring pesticides like neem oil or diatomaceous earth with no or little impacts to beneficial insects are also considered a type of conservation biological control.

Finally, there are mechanical and physical controls that simply involve removal of pests by hand or exposing pests overwintering in the soil to potential desiccation by tiling. Floating row covers and netting that block access to crops by pests are good examples of physical controls. Sticky traps can also be used for physical control and can function as a monitoring tool for pest activity if used at the right time of the season. A core assumption of IPM involves careful monitoring and correct identification of pest species, so that informed decisions related to effective control techniques can be considered.

At the core of IPM is the goal to reduce the use of insecticides, thus their use is considered a last resort after previous tactics fail. (Hajek 2004) The type of insecticide should be matched with the pest and the instructions for its application and should be carefully followed.

The diversity and sheer number of insect species on the planet is amazing. Experts estimate that there are about two million species of insects currently identified that are grouped into 28 recognized insect orders, which accounts for about 80 percent of total animal species on the planet. (NMNH 18) While that alone is extraordinary, many scientists believe this value does not include the many unidentified species in remote areas of the world such as tropical forests that could raise the total number to as many as 30 million individual species worldwide. Regardless of the final tally, the vast assortment of insect shapes, colors, behaviors, and importantly

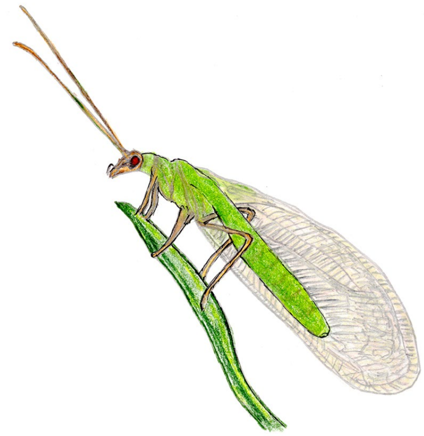
interactions with other animals in is truly astounding. Insects have inhabited the planet for over 400 million years and have evolved into a diverse array of species that dominate many of the planet's food webs. Their biodiversity forms a critical and fundamental component of the many ecosystems that pervade the planet. Although many people may not realize, we are ultimately members of the planet wide ecosystem and have much to gain or lose by being responsible protectors of all animals, but especially insects. Indeed, they may prove to be a solution to many human and environmental challenges.

Pestiferous insects will continue to challenge gardeners everywhere, but I believe I have shown that even their presence is essential to the overall balance and stability of a healthy garden habitat. My hope is that this story and perspective can potentially inspire the use of natural and organic techniques for control of pests across gardens and serve as a catalyst for greater appreciation of insect diversity in everyone's garden oasis.

Figure 40: Chris Tankersley with his first honeybee package.
Photo credit: C. Tankersley.

Select illustrations by author:

Ladybird Beetle *Hippodamia convergens*



Common Green Lacewing *Chrisoperla carnea*

Flame Skimmer *Libellula saturata*

Hoverfly *Allograpta obliqua*

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