RHODE ISLAND POLLINATORS AND AGRICULTURE

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INTRODUCTION

To address concerns regarding pollinator populations in the state of Rhode Island, the RI Natural Resources Conservation Service (NRCS) and the Heinz Center have collaborated on a project to promote populations and increase knowledge of pollinators throughout the state. We interviewed local farmers to gain a better understanding of current farming practices and their effects on bee populations. We also consulted a number of apiary and agricultural experts during the research phase of the project. The final product is this manuscript describing various native and managed pollinator species, their habitat requirements, and suggested best management practices that have the potential to help promote the growth and stability of these populations in Rhode Island.

BACKGROUND

Pollination services from native and managed species greatly impact the agriculture industry. Recent declines in pollinator populations have increased concerns for food security, food quality and farming practices around the world. There is not one specific source for the decline of honey bee populations but rather a combination of factors; known as Colony Collapse Disorder (CCD) (Mullin et. al., 2010). CCD is characterized by large numbers of dead adult bees surrounding the colony, with the queen and eggs remaining virtually unharmed (Mullin et. al., 2010). Factors contributing to CCD include disease, mismanagement of hives, introduction of invasive species, GMO crops, and chemical contamination through disease management and pesticide use (Kluser & Peduzzi, 2007; Watanabe, 2008). The largest declines in the United States have been observed in honey bees, the most heavily managed pollinator species; however, there have also been sharp declines in native populations, such as bumble bees (Watanabe, 2008; National Research Council, 2007; Goulson, 2003).

A concern for population declines of pollinators is widespread because there are so many benefits accrued from pollination services. Animal pollination is required for nearly three-quarters of the 240,000 flowering plant species worldwide (National Research Council, 2007). Pollination is vital to agriculture, as nearly all of the fruit, vegetable and seed crops that are produced and used for fuel, pharmaceuticals, animal feed, and food consumption require animal pollination (National Research Council, 2007). Roughly one third of all food crops produced require insect pollination (Goulson, 2003). Native pollinator populations have the ability to provide sufficient pollination services for crops; however, agricultural intensification, habitat fragmentation and habitat loss have all produced negative effects on these species (Kremen et. al., 2002; Julier & Roulston, 2009). If populations continue to decline, there could possibly be an overall decline in crop production and an increase in food prices (Kluser & Peduzzi, 2007).

RHODE ISLAND AGRICULTURE

It is estimated that the “green-related” sector contributes $1.7 billion annually to Rhode Island’s economy (RINLA et. al., 2012). According to a recent Economic Impact Study conducted by RINLA et. al. (2012), industries included in Rhode Island’s “green-related” sector are agriculture, landscape, floriculture, golf courses and other agricultural service-related operations. Of the approximate 670,000 acres that encompass the state of Rhode Island, ten percent of total land acreage, roughly 67,000 acres, is utilized by agricultural operations (Economic Research Service, 2013). Rhode Island farms are extremely diverse and range in size from very large to small backyard operations; however, the average size of a farm in Rhode Island is 56 acres (Economic Research Service, 2013). Rhode Island farms are also typically very diverse in the items they produce, and the state is a leader in the country for direct sales of produce from farms to consumers (Karp Resources, 2011). Many of these transactions take place directly at farms, as well as farmers markets and farm stands across the state.

Although agriculture is only one component of the state's "green-related" sector, agriculture has a major impact on the Rhode Island economy. Major commodities include livestock, dairy, aquaculture, nursery and greenhouse stock, vegetables, and sod production. Each of these commodities provides Rhode Island constituents with varying degrees of income, employment opportunities and food products. The largest of these agricultural operations include nursery, greenhouse, floriculture and sod production (Karp Resources, 2011; National Crop Insurance Services, 2013), which total 61.8% of the state's agricultural economy (National Agricultural Statistics Service, 2007). The second largest commodity group constitutes 12.3% of the agricultural industry and includes vegetables, potatoes and melons (National Agricultural Statistics Service, 2007). According to 2008 cash receipts, nursery and sod operations contributed roughly $42 million to Rhode Island's economy, while vegetables totaled roughly $7.5 million in sales (RI Agricultural Partnership, 2011). Although many other economically important food items are produced in Rhode Island, this report will generally focus on greenhouse crops, vegetables, and fruits for the purposes of pollinator populations.

RHODE ISLAND BEES

Rhode Island has a large number of bee species, despite its small size. Honey bees are the primary managed species, although the majority of bees are actually native. This is because Rhode Island does not have the commercial industry for bees that larger states do; in fact, the majority of RI farmers are also beekeepers or have their own hives on property (J. McGuire, personal communication, October 2012). Although honey bees are the most commonly managed bee species for pollination, bumble bees, specifically the species *Bombus impatiens*, have some standing as a managed species in Rhode Island as well.

The species described in detail throughout this manuscript comprise only a short list of the species present in Rhode Island. There is little information known about most native bee species; however, what is known suggests that many bees share similar foraging requirements. Likewise, many bees share similar nesting requirements based on their preferred nesting location (ground-nesting, tunnel-nesting, and social nesting).

Table 1 of the Appendix provides a summarized chart of the common bee genera discussed in the subsequent sections.

1. Social and Solitary Behavior

It is important to know the similarities and differences between social and solitary bee behaviors because it allows further understanding of each individual species. Sections 1.1 and 1.2 provide detailed descriptions of social and solitary bee behaviors, and provide the necessary background to fully understand the species that are depicted throughout the Rhode Island Bees portion of this manuscript.

1.1 Social

Eusocial bees, such as honey bees, live in very complex colony systems with several generations present at any given time. Social behavior in bees varies based on species; however, all eusocial bees live in a family structure called a colony. A colony consists of a queen, worker bees and drone bees (Toth, 2007). The females are born into their different social status as workers or queens. Worker bees are females that rarely reproduce, act as the primary foragers for the colony, and also care for offspring (Toth, 2007). The worker bees build and maintain the nest, care for the brood, and collect the pollen or nectar for the colony food source. Queens specifically lay eggs, and are also cared for by worker bees. The drone bees are the males in the colony that are born solely for mating with the queen bee (Toth, 2007).

Some bees, including bumble bees (genus *Bombus*, family *Apidae*), carpenter bees (subfamily *Xylocopinae*), and sweat bees (family *Halictidae*), live in smaller colonies. A colony can be as small as having only two adult females, one as the queen and the other as the worker (Michener, 2007). These colonies often begin with a single solitary female, but after daughters are reared the nest becomes a colony; these are known as primitively social bees (Michener, 2007). According to F. Drummond (personal communication, March 2013), less social bees may also aggregate in a communal structure where multiple reproductive females live in a single nest, sharing defensive responsibilities. Although there are varying forms of social behavior in bees, honey bees, and bumble bees are the two most social species in Rhode Island.

1.2 Solitary

Solitary bee species make up the vast majority of all bee species and exhibit very different nesting behaviors than social bees. A solitary female individually creates a nest, lays eggs and provides food for her young (Michener, 2007). Typically she will either die or abandon the nest before or shortly after the eggs she has provisioned hatch (Michener, 2007). Solitary males generally emerge from their pupae earlier than the females. This allows them to be ready to mate as soon as the females emerge (Ramel, 2000). Once females have emerged and mated they build their own nest, which generally occurs the year after they are laid as eggs. These nests can often be found in close proximity to other females, depending on species, but they are all still individualized (Ramel, 2000). According to G. Ramel (2000), these bees tend to nest somewhere near the location where they emerged, including in dead wood, crevices, well-drained soil and other suitable habitats. Each species has their own requirements for a nesting site, which is why they may return to the area from which they emerged.

Solitary bees can be highly efficient as pollinators. They tend to work faster and for longer hours than social bees because their life cycles are typically shorter than those of social species (Delaplane & Mayer, 2000). It is also typical to find that most solitary bees are more specialized pollinators than honey bees. Again, because they have shorter lives than honey bees they tend to have pollination preferences toward plants that bloom during the flight period of their life cycles (Delaplane & Mayer, 2000). This characteristic of solitary bees can be very beneficial to growers.

Many solitary species can be more specialized and more efficient in pollinating crops on a per bee basis (Garibaldi et. al., 2013). However, there is minimal information available about whether this pollination is similar, inferior, or superior to the population size of honey bees (Delaplane & Mayer, 2000). Because honey bee colonies have so many more individuals, it is not certain whether their numbers ultimately produce the same type of pollination efficiency as solitary bees with lesser numbers on a given crop.

Native solitary species have been observed as more frequent floral visitors to watermelon, tomato and pepper plants than honey bees by Winfree et. al. (2007). Despite these findings, Winfree et. al. (2007) did note that pollination services are not equivalent to floral visitation; however, increased frequencies in visitation will likely result in an increase in pollination. Garibaldi et. al. (2013) also found that native bee visitation strongly influences fruit set in crops, even more than honey bee visitation regardless of whether the honey bees are from a feral or managed colony. It has also been determined that honey bees, although typically seen as the best pollinator for food crops, do not maximize pollination or fruit set compared to native bees (Garibaldi et. al., 2013). This is even true for crops where honey bees are commonly used in high densities such as blueberries, watermelon, and almonds (Garibaldi et. al., 2013).

2. Bees in Detail

2.1 Honey bee (Apis mellifera)

Honey bees are not native to North America and were introduced from Africa and eastern or western Europe for agricultural purposes (National Research Council, 2007). The vast majority of honey bees in North America are managed for pollination; however, some colonies leave their managed hives in search of a new hive location. When these managed bees begin a new colony in the wild, they are classified as feral; there are no truly wild or native honey bees in North America. Therefore, most agricultural studies conducted have compared commercial honey bees with other native species, rather than comparing honey bees against their feral counterparts. Because of the lack of scientific data about feral honey bees, the information provided here will be regarding managed colony behavior and preferences.

***Apis mellifera* with pollen pouch**
Photo by: David Cappaert

Honey bees range in size from small to large, with moderately hairy bodies (Michener, 2007). They have characteristic black and yellow, sometimes orange, stripes that define their species. These animals are highly social and live in large colonies with complex social structures.

Nests can either be exposed or constructed in a hive (Michener, 2007). The nests are made exclusively of wax, secreted by the bees, that is shaped into a comb-like structure (Michener, 2007). The pattern of each nest will be slightly different based on the location, size, and preferences of the colony creating it. Although the overall nest size and shape differ from colony to colony, each individual cell in the comb is the same. The cells are hexagonal and of equal size, depth, and shape regardless of its use for worker eggs, honey, or pollen storage (Michener, 2007). The only time a cell is different from the rest is if it is meant to rear a queen. Queen cells are irregular in shape and are not part of the comb, but instead hang individually from sections of brood cells (Michener, 2007).

One of the many reasons honey bees are used as commercial pollinators is that their nests are perennial (National Research Council, 2007). Unlike their unmanaged counterparts, honey bee nests survive the winter and the colonies do not restart each season (National Research Council, 2007). For this reason, it can be more economical to maintain honey bee hives, rather than purchase new bumble bee or mason bee colonies each growing season. Additionally, honey bees are highly sophisticated in their communication with other colony members, using dance and vibrations to tell each other where the best sources of pollen and nectar can be found (Thompson, 2003). This communication between individuals allows this species to be more competent as a population than their native equivalent in pollination services (National Research Council, 2007). Additionally, the large number of individuals, averaging 50,000 to 85,000 individuals per colony (F. Drummond, personal communication, March 2013), generally allows honey bees to be more effective in pollination of a given crop than bee populations with a lesser number of individuals. Losey & Vaughan (2006) did find, however, that the efficiency of honey bee pollination is typically enhanced by native bee populations.

Honey bees are also generalist foragers, which promotes pollination of a wide variety of food crops on any given farm. This lack of flower preference can distract honey bees from the blooming crop and push them toward other non-target flowers (Delaplane & Mayer, 2000; Westerkamp & Gottsberger, 2002). However, when honey bees forage, they typically forage the same species of flower per trip (Richards & Kevan, 2002). This means that if a honey bee visits an apple blossom first, then the following flower visits will also have been on apple blossoms. Each foraging trip will follow this same pattern, proving the honey bee to be a very dependable cross-pollinator (Richards & Kevan, 2002).

2.2 Bumble bees (Bombus spp.)

Bumble bees are some of the largest bees in the Northeast, ranging from medium to very large in size (Michener, 2007). They are completely covered in hair (Michener, 2007), which sets them apart from other large bee species, such as carpenter bees. They are famously colored with various patterns of fuzzy black and yellow stripes, and they are typically found in cooler climates across North America and Europe (Michener, 2007).

Bumble bees have many similarities with honey bees, including their preference for social nesting. However, despite being social and living in colonies, they are much less social than honey bees and live in vastly smaller colonies (Magrum & Magrum, 2013). The nests are also annual, with the colony dying off at the end of a season and only the queen overwintering (Michener, 2007; Magrum & Magrum, 2013). These nests are commonly established in old rodent nests, old bird nests, bunch grasses, and vegetation (Michener, 2007). The nests are maintained by worker bees, which bring in additional nesting materials throughout a season to preserve the roof and structural integrity of the expanding colony (Michener, 2007).

Bombus impatiens
Photo by: David Cappaert

Bumble bees are also unable to communicate the location of pollen and nectar sources the same way as honey bees. This can be an advantage of bumble bees as pollinators because an individual that finds a superior pollen or nectar source at a non-crop flower cannot communicate the location of that source to other colony members (Delaplane & Mayer, 2000). Because they cannot communicate well, they are less likely to get distracted away from the target crop.

As a group, bumble bees are important pollinators in agriculture. *Bombus spp.* has the ability to perform buzz pollination, or sonication, which is a process that uses bodily vibrations to release pollen that is firmly attached to flower anthers (Loose et. al., 2005). This pollination process is vitally important to the pollination success of many food crops (MacCulloch, 2007), such as blueberry, cranberry, tomato, eggplant, and pepper. There have been multiple studies that focus on the success of bumble bees as a managed pollinator species due to their ability to utilize buzz pollination. Studies have specifically focused on using bumble bees in greenhouses where peppers, tomatoes, and other crops are grown (National Research Council, 2007). Although bumble bees are commercially available, it is likely that native populations are easier to attract (Magrum & Magrum, 2013). Bumble bees are highly susceptible to some of the same diseases and parasites that have been known to destroy honey bee colonies, making it difficult to maintain a commercial colony of bumble bees (National Research Council, 2007).

In addition to performing buzz pollination, bumble bees are also generalist foragers, which are beneficial to the agricultural industry because they pollinate a variety of crops in addition to those requiring buzz pollination. Some examples of bumble bee pollinated food crops include tomatoes, cucumbers, eggplants, peppers, potatoes, blueberries, melons, cranberries, cantaloupe, and other berries (MacCulloch, 2007; Magrum & Magrum, 2013). Bumble bees have also been identified as the single-most efficient and effective pollinator of cranberry crops (Loose et. al., 2005). They are faster, more efficient, and more consistent about pollen foraging on cranberry flowers than honey bees (MacKenzie, 1994).

Bumble bees are also more tolerant of inclement weather and will visit flowers in rain and windy conditions, while other species will not (Delaplane & Mayer, 2000; Richards & Kevan, 2002). Additionally, bumble bees have long tongues, providing an advantage over other bee species to pollinate certain crops (Richards & Kevan, 2002).

2.3 Squash bees (Peponapis spp. & Xenoglossa spp.)

Squash bees are unique because they are oligolectic, meaning they only pollinate specific crops (Roulston & Goodell, 2011), in this case from the *Cucurbitaceae* family. Cucurbits include cucumbers, pumpkins, melons, gourds, and squashes of all varieties. The most common squash bee is *Peponapis pruinosa*, which is present almost anywhere that squashes are grown (Cane, 2009). They are typically found throughout Canada, the United States, Mexico, and farther into South America (Cane, 2009).

Peponapis pruinosa
Photo by: Susan Ellis

As pollinators, squash bees begin pollination much earlier in the day than do other bee species (Wood, 2008). Once blooms close midday the squash bees become fairly inactive and return to their nests. Some males become trapped in the closed flowers and will even spend the night inside the closed flowers (Wood, 2008; Magrum & Magrum, 2013). Their life cycles are ultimately dependent on cucurbit blooms so they do not require year-round food sources (Surcică, 2011). Also, because of their proficiency and effectiveness in pollinating cucurbit crops, squash bees essentially eliminate the need for honey bees to pollinate these crops (Cane, 2009). This allows honey bees to be used elsewhere, which can be economically beneficial to farmers since honey bees are in high demand with low supply (Wood, 2008).

Squash bees are solitary ground nesters that establish their nests at the base of cucurbit plants or at the edge of a field (Surcică, 2011; Delaplane & Mayer, 2000). Their nests consist of one main tunnel that terminates into small chambers and branches where the eggs are laid (Wood, 2008). The larvae remain in the ground developing and hibernating for the entire season (Surcică, 2011). The tunnels that squash bee adults create are typically 5 to 10 inches deep (Surcică, 2011). This specific depth in combination with the incubation period of the larvae, make them extra susceptible to death from tilling practices. It is best to attempt to avoid deep tilling to decrease direct mortality.

Although this species is highly vulnerable to death from tilling, populations can still be successful because of their strong philopatry (Julier & Roulston, 2009). This is the behavior of returning to an individual's place of origin (Yanega, 1990). If squash bees establish their nests in areas that are safe from tilling or other ground disturbance, rather than near cucurbit plants, then populations may flourish because of their highly philopatric behavior (Roulston & Goodell, 2011). Another factor is that *Peponapis pruinosa* is fully dependent on crops in the *Cucurbitaceae* family; therefore, they are not dependent on other floral resources for forage and new bees will continue to establish nests where the crop is planted, regardless of tilling fatalities (Julier & Roulston, 2009).

2.4 Mason bees (Osmia spp.)

Mason bees can be a variety of colors. Some are shades of black or brown, while others have a blue or green metallic coloring (MacCulloch, 2007). They tend to be small to medium in size and are solitary, cavity nesters by nature (MacCulloch, 2007). Cavity-nesting is a type of tunnel-nesting; they do not create their own tunnels to nest in, but rather find preexisting nests or cavities to inhabit. Due to this preference, man-made nest blocks and stem bundles are extremely attractive to mason bees. There are also commercially available mason bee nest blocks, especially for the blue orchard mason bee.

An Orchard Bee
Photo by: K.S. Matz

The most common native species of mason bee is *Osmia lignaria*, the orchard mason bee. In recent years there have been many studies that examine the effectiveness of their use as managed pollinators. Mason bees tend to be polylectic, or generalist, foragers; however, they tend to demonstrate a strong preference for fruit trees. This preference has led to their use as a managed pollinator species (Bosch & Kemp, 2002). *O. lignaria* has been found to be a very useful and efficient pollinator of apples, almonds, and other tree fruits (National Research Council, 2007). Similar to bumble bees, mason bees are also willing to continue flight during inclement weather (Richards & Kevan, 2002), which provides an advantage over other species for pollination services.

2.5 Sweat bees (Halictus spp., Lasioglossum spp. & Augochlorella spp.)

The Halictidae family is one of the most common groups of bees found on farms and in the wild. This group of bees tends to be most abundant in the late spring and summer months. Their common nickname "sweat bee" stems from the bees' affinity for the taste of salt in human sweat (MacCulloch, 2007). Halictids tend to be small in size and are a range of colors from dull browns to metallic blue and green (Magrum & Magrum, 2013; MacCulloch, 2007).

Sweat bees are commonly ground-nesting bees; however, there are some instances where they will create nests in rotting wood as well (Michener, 2007). They are traditionally a solitary group of bees with a variety of nesting habits. Some sweat bees will nest individually, far removed from others, while other sweat bees will be found in densely populated areas using shared entrance holes (Magrum & Magrum, 2013). They typically produce only one generation per year (MacCulloch, 2007), although some sweat bees demonstrate a variety of social behaviors. While some females will share a common entrance and construct individual cells separately, others will communally share the nest. In this case, there will be a few egg-laying females with the others acting as workers to construct the cells, feed the broods, etc. (Microsoft Encarta Online Encyclopedia, 2007). One difference between this sociality of sweat bees and other social groups, such as honey bees, is that the adults do not have sophisticated communication systems to utilize to exchange information with one another (Microsoft Encarta Online Encyclopedia, 2007).

Photo by: Susan Ellis

Due to their vast numbers, the ability to perform buzz pollination, and their generalist preferences, halictids are important in agriculture. Buzz pollination is the act of holding onto the anther of a flower and using full body vibrations to release pollen (Larson & Barrett, 1999). This type of pollination is specifically required for certain crops, such as blueberries, cranberries, tomatoes, and others. Sweat bees, along with other buzz pollinating species, are able to pollinate these crops more efficiently than species which cannot perform buzz pollination (National Research Council, 2007). These bees are also able to pollinate flowers of crops that do not require buzz pollination. All of these traits together demonstrate how valuable sweat bee populations are to the overall crop production of a farm.

2.6 Carpenter bees (Xylocopa spp.)

It is very common to mistake large carpenter bees, such as *Xylocopa virginica*, for bumble bees since they are both large, robust bees. Carpenter bees, however, tend to have less hair and a shiny abdomen. Smaller species have much less hair and have more blue-black coloring than some of the larger species (MacCulloch, 2007).

Carpenter bees are classified as tunnel-nesting bees due to their strong preference for establishing nests in wood. They typically burrow into solid wood, with various tunnels branching out in the direction of the wood grain (Michener, 2007). Some smaller species prefer to use preexisting tunnels from beetles in dead wood or snags, while the larger carpenter bees will create their own new nests (Keaser, 2010; MacCulloch, 2007). It is common for these bees to target soft woods, while ignoring hard woods, painted wood, or wood with bark (Magrum & Magrum, 2013). Although most carpenter bees prefer solid wood, some species do nest in the hollow stems of plants (Michener, 2007).

These bees have very acute maternal instincts and care for their offspring, unlike many other solitary species (Michener, 2007). Because of this, carpenter bees tend to have a higher survival rate than other species laying the same number of eggs. They also tend to live longer than most solitary species (Magrum & Magrum, 2013). This characteristic sets carpenter bees apart from many other solitary species.

Carpenter bees have not been used extensively in agricultural research projects; therefore, there is little information about specific food crops pollinated by native carpenter bees. Despite the lack of research as pollinators, it is known that they are capable of sonication, or buzz pollination (Delaplane & Mayer, 2000), similar to the bumble bees and sweat bees previously discussed. This can prove useful in the pollination of tomatoes and other such crops. There is minimal information about their preferences toward buzz pollinated crops, and it has been accepted that they tend to be active generalists when in a natural setting (Keasar, 2010). Carpenter bees visit any flowering plant that is available and attractive to them, which can complement the work of both honey bees and non-generalist species of bees.

***Xylocopa virginica* visiting a yellow flower**
Photo by: Karan A. Rawlins, University of Georgia, Bugwood.org

Conversely, carpenter bees can also be nectar robbers. They do pollinate many flowers and crops, but they do not always visit a flower in a way that allows pollen collection (Gerling et. al., 1989). Specifically, carpenter bees will create a slit in the side of a flower in order to get to the nectar while avoiding all contact with pollen; this process is known as flower robbing (Kaesar, 2010; Delaplane & Mayer, 2000). Sometimes this can increase the amount of flower robbing by other bee species who would have otherwise visited the flower normally (Delaplane & Mayer, 2000). Again, the extent of this effect on other species has been observed, but limited information is available because of a lack of scientific research on the subject.

2.7 Mining bees (Andrena spp.)

These bees are typically hairy and range from small to large in size. Mining bees can be easily identified by a variety of colors; all black, gray haired, red haired, metallic blue or green (Michener, 2007). They are typically most active in the early spring.

Mining bees are solitary, ground-nesting insects by nature (Michener, 2007). These bees usually only produce one generation per year; however that does not necessarily mean they will only have one brood. The offspring of these bees mature and overwinter as adults in their nest cells and therefore will not reproduce until the following year when they finally emerge (Michener, 2007). There are a few specific *Andrena* species that do produce two generations, but it is not common throughout the genus (Michener, 2007).

Mining bees are either polylectic pollinators, meaning they are generalists and will visit any flower available to them, or oligolectic pollinators, visiting only a small number of specific flowers (Michener, 2007). The preference for these bees will depend on the species, but both are beneficial for farming purposes. Some common crops pollinated by mining bees include cucumbers, watermelon, apples, and cantaloupe (MacCulloch, 2007; Park et. al., 2010).

BASIC HABITAT REQUIREMENTS FOR BEES

1. Foraging

1.1 General

Identifying areas that will naturally attract bees and other pollinators is easy. Often times there is variance in the height and depth of vegetation present, flowers that bloom steadily throughout the growing season, and a nearby water source. An area that allows weeds, especially flowering ones, to grow will also attract pollinators. These areas are generally undisturbed and allow bees to forage as needed. A variety of flower color, shape and size is also more attractive to bees than a uniform grouping of one flower type (Vaughan & Black, 2006). The more variance in flower type and bloom period, the higher the likelihood that the entire community of bees and other pollinators will be attracted to a certain site. On a farm it is important to have flowering plants that can serve as alternate food sources for bees when crops are done flowering. A summary of the following descriptions can be found in Table 3 in the Appendix.

1.2 Flower Traits

Although bees prefer a variety of flowers, they to favor flowers with certain color ranges, nectar guides, petal shapes, and nectar presence. Flowers that are any shade of white, blue, or yellow will be the most attractive to bees (Ley, 2008). These flowers should also have pollen, which is usually sticky and scented, accompanied by sweet, mild-smelling nectar (Ley, 2008). Flowers with a combination of these traits are the most appealing to bees.

In order to find the nectaries in flowers, bees use nectar guides, which are color patterns surrounding the center of the flower where nectar and pollen are produced (Hansen et. al., 2012). They contrast the color of the remainder of the flower petals, too. These patterns direct the bees to the flower center, where they are rewarded with nectar and pollen.

The most attractive flower shape to a bee is one that is shallow for easy access to nectar and pollen, somewhat tubular, and has an ample landing platform (Ley, 2008). The landing platform is important because bees generally stop at each flower while foraging, rather than engaging in continuous flight throughout the collection process. The continuation of flight throughout the foraging process will differ among species, especially in regards to whether they have long or short tongues (H. Ginsberg, personal communication, April 2013).

2. Nesting

2.1 General

There are three main features that every nest requires: adequate sunlight, nearby water, and an ample food supply. It is vital that an appropriate food supply is available for bees throughout the agricultural growing season. This will allow larger and more diverse populations to populate the area, ultimately increasing chances of crop pollination. Sunlight is important in warming the bodies of bees, so it is best if nests are exposed to morning sunlight.

Additionally, it is important that nesting materials and resources are available to bees as well as the habitat where they will nest. Some species use mud and leaves to create individual cells, while others use plant resins or secreted materials. For example, many species in the family

Megachilidae use leaves, mud, and resin to create individual brood cells (Roulston & Goodell, 2011). According to Roulston & Goodell (2011), if these nesting materials are unavailable for bees to use, they will be less successful in establishing nests. In the subsequent sections are details describing specific nest requirements based on nesting behaviors and preferences.

2.2 Tunneling or Wood-boring Bees

Bees that create their own burrows, such as the carpenter bee and many *Osmia* (Mason) species, tend to favor soft woods, dead wood, or snags for their nest location. Populations that nest in dead wood or live trees have become increasingly stressed because much of their nesting habitats have been lost due to agricultural intensification (Ghazoul, 2005). They will sometimes utilize old beetle tunnels or holes in wood, but typically prefer to construct their own new nests instead. This is important to keep in mind when creating artificial nest sites for these bees.

2.3 Cavity-Nesting Bees

Bees that use preexisting cavities or holes are known as cavity-nesting bees. For example, many *Osmia* species are opportunists, and despite their preference for excavating their own nests in soft pith woods such as elderberry or raspberry, they will sometimes accept pre-existing holes for their nests instead (F. Drummond, personal communication, March 2013).

Cavity-nesting species do not excavate their own nests and characteristically rely on old bee nests, beetle tunnels, and other such holes to establish their new nests. When using a pre-existing site, females will choose their nest based on the diameter of the entrance hole, since species vary in size (National Research Council, 2007). Some cavity-nesting species choose soft, pithy, hollow-stemmed plants as their nesting location (Vaughan & Black, 2007). Cavity nesters have the same general requirements as tunnel-nesting bees, except that they seek out preexisting hollow spaces rather than creating their own.

2.4 Ground-Nesting Bees

Although all ground-nesting bees make their nests in the soil, they do have different preferences based on species. Some prefer loose, sandy soils while others look for smooth, packed soils (Mader et. al., 2011). Typically in Rhode Island, solitary species will look for sandy or sandy loam soils rather than clay or organic soils (F. Drummond, personal communication, March 2013). Some species also prefer a flat, bare ground while others want a vertical bank of soil (Mader et. al., 2011). Some will even burrow near the base of plants, which is true for squash bees. Despite these differences, there are many similarities in the nesting areas that these species choose.

When creating a good habitat for ground-nesting bees, it can be helpful to observe what current conditions are being utilized and are preferred by existing bee populations. It can be difficult to locate the nests, as most of the activity is underground (Mader et. al., 2011). The entrance hole to each nest will vary in size based on the species that is occupying it, and will vary from 1/8 inch to a half inch in diameter, depending on the species (Mader et. al., 2011). Some bee nest entrances will even look like ant mounds, with a small pile of dirt surrounding the entrance (Mader et. al., 2011).

RECOMMENDATIONS FOR DESIGNATED BEE FORAGING HABITATS

1. General

There are many key factors to keep in mind when creating a new bee habitat. The more variety in flower and plant type, the more likely it is that a variety of bees will be attracted to that area. Like most animals, bees need both food and water sources near their nests in order to survive. Bees are fairly adaptive, so the actual location selected as a new bee pasture, will be effective and beneficial to populations as long as their key survival needs are met. It is ideal to maintain and conserve existing habitats before creating or restoring new areas for pollinators (National Research Council, 2007). Preexisting areas will frequently already have an adequate mix of native and nonnative species that cater to the majority of pollinator needs; however, these sites are often rare on heavily managed farms (Vaughan & Black, 2006; National Research Council, 2007). Identifying present habitats can be beneficial because they do not need to be established, only enhanced. These habitats can be easily found near hedgerows, riparian buffers, or other natural areas such as a wooded edge (Vaughan & Black, 2006).

The most important thing to remember when choosing a location for a new bee habitat is that ultimately its placement needs to be appropriate for the operation of the farm. Although bees have requirements and preferences for where the habitats are placed, in the end, the chosen location must be convenient and manageable for the farm. It would be counterproductive to establish a new bee pasture in the spring only to realize it is in the way of machinery or everyday farming operations and must be relocated for the next season.

A good example of a field buffer with sun exposure, wildflowers, and proximity to other forage and nesting sites
Photo courtesy of USDA NRCS

2. Site Selection

2.1 Size of Habitat

The size of a bee pasture can be crucial to its success in encouraging population growth of native bees and other pollinators. If an area is too small, it will not provide enough territory for multiple colonies or populations to forage, nest, etc. A site is best if larger in size and close to other patches of foraging habitat, whether natural or man-made (Vaughan et. al., 2009; Mader et. al., 2011). It is ideal to have 1 to 2 acres of bee pasture per 25 acres of cropland (Vaughan et. al., 2009).

Place the bee pasture close to a property line, a wooded edge, another bee-friendly habitat or other boundary lines rather than establishing one in the middle of an open field (National Research Council, 2007). This type of placement will encourage bees to establish and expand their colonies or nests in those areas. Also, having a bee pasture with obvious boundaries will aid in preventing weed encroachment (Vaughan et. al., 2009; Mader et. al., 2011), which is beneficial because it minimizes the amount of maintenance needed to maintain that location.

2.2 Sun Exposure

Sun exposure is crucial to the health and well-being of bees. They need the sun to warm their bodies in the morning in preparation for flight throughout the day. When establishing a new bee habitat, make sure that there is ample sun exposure throughout the day (Mader et. al., 2011). Full-sun is not necessarily required, as the bees and their nests can overheat, but it is important to provide sunlight for multiple hours throughout the day (Vaughan et. al., 2009; Mader et. al., 2011). This full-sun exposure is also important for plants in the bee pasture (Vaughan et. al., 2009).

2.3 Vacant and Unmanageable Land

Sometimes the perfect place to establish a new bee environment is on land that is otherwise unusable (Mader et. al., 2011). For example, septic fields, slopes too steep to mow, ditches, areas surrounding utility poles, retention ponds, etc., can all serve as ideal locations for bee pastures (National Research Council, 2007; Mader et. al., 2011; Vaughan et. al., 2009). These locations allow the utilization of land that is otherwise inadequate for crop production, which prevents the need to sacrifice ideal crop land for pollinators. These parcels of land can be used as either foraging habitat or nesting habitat for bees (Vaughan et. al., 2007).

2.4 Distances from Nests and Other Forage

Another consideration for the location of a bee pasture is the flight distance of bees. Distance to foraging resources is very important because it can facilitate interactions between plants and animals that would otherwise not occur (Vaughan et. al., 2009; Greenleaf et. al., 2007). These interactions can be important in supporting species richness and can also prove valuable to pollination services. In an agricultural setting this is especially important when crops require specific insect traits for pollination (Greenleaf et. al., 2007).

A blooming hedgerow with a mix of wildflowers, grasses, and forbs at Singing Frogs Farm
Photo by: Noelle Johnson

The actual distance any one bee will fly from its nest to a flower depends on the species (Walther-Hellwig & Frankl, 2000), but there are some general guiding principles to recognize. Smaller bee species fly no more than 500 feet from their nest to any foraging site (Mader et. al., 2011; Vaughan et. al., 2009). Typically, larger bee species will fly farther distances during forage trips than their smaller counterparts (Greenleaf et. al., 2007)). Some larger bees, like the bumble bee, will fly more than a mile to reach their forage (Mader et. al., 2011).

As the distance between nesting and forage habitats increases, the presence of pollinators and efficiency of pollination at those forage sites decrease (Ricketts et. al., 2008). This is especially true for native species, rather than those that are managed (Ricketts et. al., 2008). Because of this, on heavily managed farms or areas with intense agricultural practices, it is ideal not to place forage plants any more than a few hundred feet away from a nesting site (Vaughan et. al., 2007; Roulston & Goodell, 2011; Mader et. al., 2011). This can accommodate the flight restrictions of smaller species and prevent habitat fragmentation, which is a common side effect of agricultural intensification (Walther-Hellwig & Frankl, 2000). On more heavily managed farms it is good to have blooming patches, including flowering crops, separated by no more than 500 feet (Mader et. al., 2011). The distance between nests and forage habitat is very important to pollinators and will ultimately determine the productivity of bees as pollinators (Ricketts et. al., 2008; Roulston & Goodell, 2011). The quality and size of the bee habitat is important in affecting their willingness to visit flowers and specific crops.

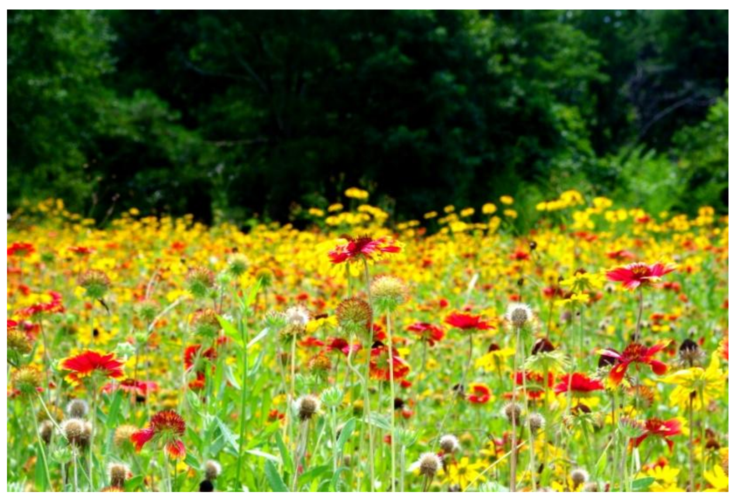
3. Site Design

The design of the space chosen as a new bee pasture is more influential than the actual location. Bees are most attracted to clumps of one single flower species at least 3 feet in diameter (Mader et. al., 2011). This reduces a bee's energy expenditure and aids in increased pollination efficiency since the flowers are all in one place (Mader et. al., 2011). Although this is true, bees also prefer to have a variety of flowers to visit. When planting flower clumps, randomly place them throughout the bee pasture and have them vary in species (Mader et. al., 2011). It is okay to have multiple clumps of one flower species, but it is important that they are not too close together. This type of planting can help bees to remain efficient during their forage trips.

4. Vegetation Selection and Planting

4.1 Flowering Plants

Plant selection for a bee pasture is tremendously important. If plants that bees and pollinators are specifically attracted to are not chosen, then the bee pasture will be less effective in increasing populations on site. It is also important to choose plant material that will thrive in the sun and soil conditions of the bee pasture area (Vaughan et. al., 2009). Table 4 in the Appendix provides a list of possible plants that may be incorporated into a pollinator-friendly habitat.



A variety of wildflowers grow together to create a successful bee pasture
Photo by: Flickr user NatalieK

The best range of diversity is between 8 and 10 different plant species. Having 10 different flowering species is ideal since any less than 8 will be less attractive to pollinators (Mader et. al., 2011). If more than 10 species are included, note that pollinator diversity tends to level out when there are 20 or more flowering species available in a given area (Mader et. al., 2011; Vaughan et. al., 2009). In a recent study, it has been shown that solitary bee populations have been more abundant in areas with a higher diversity of weedy or flowering plants (Winfree et. al., 2007). It has also been observed that *Bombus* populations are highly dependent on the amount of flowering forage available, and may show vast declines if floral resources are suddenly diminished (Winfree, 2010).

Choose plant types based on which target pollinators are desired. For example, if butterflies are desired then choose bright-colored, tubular flowers and if bees are being targeted then choose more shallow flowers. Each group of pollinators is discussed in detail with their respective preferences for flower type throughout this document, which can be used as a reference. In addition, it is helpful to include some native vegetation as well as non-natives (Mader et. al., 2011; Ley, 2008).

4.2 Bloom Period

Aside from type and number of different plant species, it is also important to consider bloom periods of each plant. As mentioned previously, bees and other pollinators require food supplies throughout the active season, which are especially important once the target crop has ended its bloom period (Vaughan et. al., 2007). Selected vegetation should have some amount of overlap between different bloom periods to ensure that there is never a shortage of forage resources for pollinators (National Research Council, 2007). An important note about bumble bees is that they do not store food for more than a few days, so a season-long food supply is vital to the success and health of these colonies (Richards & Kevan, 2002). In addition to bumble bees and other generalists needing forage throughout the season, it is also important to maintain a supply of flowers that will satisfy specialists' foraging requirements (Roulston & Goodell, 2011).

It is essential to include early- and late-blooming plants since these serve as initial and final food sources for pollinators that overwinter in Rhode Island (Mader et. al., 2011; Ley, 2008). Early-blooming plants serve as a food source for early emerging bee species and bee queens, such as bumble bees, sweat bees, and mining bees (Mader et. al., 2011). Similarly, late-blooming flowers serve as food sources for pollinators that are preparing to overwinter. These late-blooming flowers can be important in providing overwintering bees, such as bumble bee queens, with sufficient amounts of energy to survive the winter months (Vaughan & Black, 2006). Some good examples of late-blooming forage are goldenrod and aster varieties (Vaughan & Black, 2006).

Another principle to keep in mind is that if there are too many blooms available at the same time as a target crop, then bees may be encouraged to visit those flowers instead of the crop. This is especially true for honey bees and other generalist pollinators. To avoid this dilemma plant few species that flower during a crop's bloom period and choose the majority of plants to bloom either before or after the target crop (Mader et. al., 2011).

4.3 Grasses

In addition to providing flowering plants for bees and other pollinators, it is also crucial to include native grasses. These grasses will supply nesting habitat for bumble bees and overwintering sites for insects (Vaughan & Black, 2007). They may also serve as a host for butterfly and moth larvae (Mader et. al., 2011; Vaughan et. al., 2009). Grasses and sedges can help prevent weed encroachment because their root systems tend to be very complex, which makes it more difficult for weeds to establish themselves (Vaughan et. al., 2009). This is beneficial because it will allow labor to be focused on tasks other than keeping weeds out of the designated area.

The type of grasses chosen is just as important as the type of flowering plants. Warm season grasses, perennial clump grasses, and other species that are not likely to crowd out flowering plants are the best options (Mader et. al., 2011; F. Drummond, personal communication, March 2013; Vaughan et. al., 2009). Typically, tall grasses and cool season grasses are more likely to crowd flowering plants and forbs (Vaughan et. al., 2009). It is also crucial that at least one native species is included in a seed mix (Mader et. al., 2011). It is best to plant grasses in the fall, rather than the spring, to encourage flower growth during the growing and pollination seasons (Mader et. al., 2011). Finally, if establishing a bee habitat from seed, do not allow grasses to include more than 30 percent of the overall vegetation cover (Mader et. al., 2011). Exceeding this percentage of grasses will cause the flowering plants to be crowded out and ultimately hinder their growth.

4.4 Invasive Plants

When choosing plant varieties for a new bee habitat, it is important to note whether they are aggressive or invasive growers. Plants that are invasive have the ability to dominate an area, spreading quickly, which ultimately deteriorates plant diversity and leads to less forage resources for bees (Vaughan & Black, 2006; Roulston & Goodell, 2011). Invasive and non-native plants can also eliminate vital food sources for specialist bees, which can pose a significant problem for the growth of those populations (Winfree, 2010). These plants tend to be less harmful to generalist foragers since they may still be able to forage these plants.

These invasive species are also difficult to remove once established and can increase the maintenance need for a given area in the long run (Vaughan & Black, 2006). Some examples in Rhode Island include swallowwort, autumn olive, and multiflora rose, which can be extremely difficult to remove if allowed to encroach on a field or bee pasture (D. Gregg, personal communication, March 2013). It is advised that the county or town of the property is consulted as to what varieties may be considered invasive in that area (Vaughan & Black, 2006).

4.5 Local Resources

See Tables 5 and 6 of the Appendix for available resources in Rhode Island and New England that may be consulted for assistance with plant and seed mix selections and purchasing. There are a number of additional local, state, regional, national and online resources available as well. The provided list can be used as a reference to get started in the search for further information.

5. Bee Density Recommendations

See Table 2 of the Appendix for density recommendations of both honey bees and managed bumble bees for common crops produced in Rhode Island.

RECOMMENDATIONS FOR CREATED BEE NESTING SITES

Lists of potential consultation resources for beekeeping supplies and artificial nest construction are provided in Tables 7 and 8 of the Appendix. The lists are not inclusive of all Rhode Island or regional professional experts, but can be used as a guide to begin the research process.

1. Tunneling or Wood-boring Bees

1.1 Nest Blocks

1.1.1 Commercial Caution

Commercial nest blocks have become widely available with the growing concern for declining bee populations. While this is a new development, it is important to keep in mind that the commercial blocks may not fit the needs of all desired bee populations. For example, a nest block for blue orchard bees is made with 4x4 lumbers that have $^5/_8$ inch diameter holes (Mader et. al., 2011). These measurements are specifically suited for blue orchard bees, but these holes can pose problems for other bees. If other bees used this type of block, they would only produce male offspring because female offspring require deeper chambers to develop (Mader et. al., 2011). Depending on what species are being targeted, it may be necessary to do additional research to find out exactly what commercially available blocks will support those specific populations.

1.1.2 Location and Installation

When locating a place to install a nest block, it is best to look for a location that is protected and has direct morning sunlight, with light amounts of shade throughout the day (Mader et. al., 2011). This can be easily accomplished if the entrance of the nest faces east or southeast (Shepherd, 2008). Too much sunlight later in the day can overheat the nest and indirectly kill some of the brood or adults; however, this is uncommon in Rhode Island.

It is also best to firmly attach the nest to a major landmark that is easily identified, i.e. side of a building, an isolated tree, a fence post, etc. (Shepherd, 2008; Mader et. al., 2011). The nest block needs to be fixed firmly enough that it will not be shaken or disturbed by heavy winds; this will make the bees feel more secure in their nest (Mader et. al., 2011). If the nest is susceptible to moving in the wind the bees will not find it suitable for nesting. The height at which these blocks are placed is flexible but should be at least 4 feet off the ground (F. Drummond, personal communication, March 2013) to protect the entrance holes from water infiltration and vegetative growth (Stubbs et. al., 2000).

1.1.3 Construction

There are many possible ways to create an artificial nest block for wood-boring bees. It is important to note that the following are only guidelines and suggestions for construction of an artificial nest block. There is no guarantee that the methods provided below will prove successful. Consult additional resources for other considerations in nest block construction, some of which are available in Table 7 of the Appendix.

1. Use preservative-free lumber. Firewood or other rough woods are acceptable as long as it matches the following dimensions: 4x4 lumber is needed for drilled holes less than ¼ inch in diameter, 4x6 lumber is need for larger holes. The length of the wood is ultimately irrelevant, but roughly 8 inches in length will suffice (Mader et. al., 2011).

2. Drill holes randomly into the wood. Do not drill all the way through the wood, as bees will not inhabit cavities with openings at both ends (Stubbs et. al., 2000). If this does occur, make sure to attach a backing to the wood block (Mader et. al., 2011).
    a. It is ideal to drill holes in a range of sizes between $^{3}/_{32}$ inch and $^{3}/_{8}$ inch to account for various sizes of bees and their individual preferences (Vaughan & Black, 2007).
    b. For holes that are less than or equal to ¼ inch, the depth should be roughly 3 to 5 inches (Mader et. al., 2011; Shepherd, 2008).
    c. Holes that are larger than ¼ inch in diameter should be 5 to 6 inches deep. These deeper holes will encourage female eggs to be laid (Shepherd, 2008).
    d. If it is not possible to drill a hole at least 3 inches deep due to the length of the drill bit, then it is acceptable to only drill as far as the bit allows (Mader et. al., 2011), as some bees will likely extend the cavity as needed for their brood.

Artificial nest block with paper straw liners
Photo by: David Wright

3. The distance between holes in the wood should be roughly ¾ inch from center to center. The holes should also not be drilled any less than ¾ inch from the side of the wood block (Cane, 2010; Shepherd, 2008).
4. It is important to use a sharp drill bit. This will create a smoother tunnel, which bees prefer. If a dull bit is used, the bees may find that the tunnels are too rough to occupy. Having smooth holes will also allow the nest block to resist some basic damage that would otherwise occur from cracks or warping (Mader et. al., 2011; Shepherd, 2008; Cane, 2010).
5. It can be helpful to line the drilled holes with paper to control disease from season to season. Wrap parchment or wax paper around an item that is a similar diameter to the drilled holes to create paper straws (Mader et. al., 2011). These straws are inserted into the holes to supply a protective lining against disease and parasites.
    a. Paint the outside edge of the paper straws black or another dark color to attract bees, and insert into an appropriate sized cavity on the wood block. Dark colors are most attractive to bees because it emphasizes a cave-like appearance to the hole, which is important to nesting females. Another option is to char the front of the nest block, as this also makes the entrance holes more attractive (Cane, 2010).
6. Decoration of the outside of the nest block is up to interpretation and personal preference. Bees tend to favor dark-colored nest blocks, but light colored ones can be just as effective (Mader et. al., 2011).

7. It is also optional to attach a roof structure that will shelter the entrance holes from inclement weather (Mader et. al., 2011). An alternative to this is tilting the nest block a few degrees at a downward angle (F. Drummond, personal communication, March 2013).

1.2 Snags

A snag refers to any dead or dying tree that remains standing or has collapsed. Snags can be used as alternatives to creating wooden nest blocks. A natural way to improve habitat for wood-boring bees is to allow items such as dead trees, branches, old stumps, etc., to remain on property whenever it is safe to do so (Vaughan & Black, 2007). These areas will provide ample habitat for bees to choose from in order to create their own nests.

It is also possible to create an artificial snag if aesthetics and safety of natural snags are an issue. Create an artificial snag by drilling holes of varying sizes into a log, then erecting it somewhere on site to imitate a fence post (Vaughan & Black, 2007). This arrangement can be a very attractive location for bees (Buchmann, 2002), especially if there is adequate sun exposure in the morning hours and throughout the day. Another option is to drill holes of various diameters into stumps, dead trees, and logs already present on the property (Buchmann, 2002; Mader et. al., 2011; National Research Council, 2007).

A large log with drilled holes is an example of a snag
Photo by: Hans Weingartz

1.3 Stem Bundles

A stem bundle is a collection of hollow tubes that are tied or bundled together. Stem bundles are an effective alternative to nest blocks, snags, and other artificial nests; however, they are more prone to parasites. When installing a stem bundle nest for bees, it is important to keep in mind that the tunnels are installed so that they are horizontal to the ground (Shepherd, 2008). It is also vital that the entrance holes of the stems face the east, so that they are able to benefit from morning sun exposure.

The following are guidelines do not guarantee successful nesting of female bees but should be used as a reference when creating a stem bundle nest.

1. Find a stem-like material that has natural nodes in it. A node refers to the part of a plant’s stem where leaves grow. Nodes in hollow-stemmed plants typically have a natural cross-sectional barrier that depicts the node. These nodes are important for cutting purposes, and also serve as a natural hole ending for bees (Mader et. al., 2011). A commonly used material is bamboo stems.
2. Cut each stem just below a node in order to create a natural tube with one open and one closed end (Shepherd, 2008).

3. Secure the stems together in a tight, bundle formation with wire, string, or another effective material. It is important to make sure that when the stems are secured, all the open ends are facing the same direction. Bees will find it unattractive if open and closed ends are meshed together (Mader et. al., 2011).
4. As an alternative to tying the stems together, it is acceptable to tightly pack the stems in a container or protected structure, i.e., a birdhouse, coffee tin, plastic bucket, etc (Mader et. al., 2011).
5. Similar to the wooden nest block recommendations, it is also helpful to line these stems with paper straws to prevent the spread of disease from one season to the next (Shepherd, 2008).

A commercially available stem bundle nest for bees
Photo by: Gardener's Supply

1.4 Maintenance and Disease Prevention

Routine management and replacement is necessary to fight the spread of parasites or disease for artificial nests. Natural nests do not need the same maintenance because bees will either fight the disease themselves, or move to a new location. Also, it is unrealistic and difficult to locate, identify and sanitize naturally occurring tunnel nests. The point of constructing a nest block is to attract bees, so it is vital to keep the blocks clean and encourage their use by bees.

A nest block is generally viable for a few years before there should be concern of parasites (WSU EMGP, 2010). At the end of the nesting season it is important to gently remove paper straws from the holes and relocate, including the bees, to an unheated location, such as a barn, garage, etc. (Mader et. al., 2011; WSU EMGP, 2010). Once the straws are removed, the blocks can be disinfected with a bleach solution (WSU EMGP, 2010). Make sure there are no air bubbles in the tunnels during the disinfecting process. Store the blocks for the winter once sanitation is complete. If disinfection of the nest blocks is too time consuming, consider creating new nest blocks each season (WSU EMGP, 2010).

***Osmia spp.* entering her nest in a snag**
Photo by: Gilles San Martin from Namur, Belgium

Store the bees and blocks where they can remain at temperatures between 34°F and 38°F (Stubbs et. al., 2000). Do not store the blocks and bees in temperatures above 38°F, as this will encourage early emergence (Stubbs et. al., 2000).

Line the tunnels with new paper straws for new broods in the spring when the nest blocks are installed outdoors again (WSU EMGP, 2010; Mader et. al., 2011). The paper straws from the previous season should be placed in an emergence chamber (Mader et. al., 2011), which is a container that allows the brood from the previous season to safely hatch and emerge for the growing season.

The emergence chamber should be a dark container with a single hole that is $^{3}/_{8}$ inch in diameter drilled into the bottom of the container. Place the chamber outside, adjacent to the nest block, snag, or stem bundle (WSU EMGP, 2010). As the bees emerge from the straws inside the container, they will be attracted to the hole at the bottom (Mader et. al., 2011). They will then fully emerge and be encouraged to occupy the nearby artificial nest and lay their own brood (Mader et. al., 2011; WSU EMGP, 2010). Once the season is over, dispose of the old straws.

2. Cavity-Nesting Bees

Refer to the previous section for details on following nest recommendations for artificial tunnel nests, such as snags and nest blocks, in order to satisfy nesting preferences and needs of cavity-nesting bees.

3. Ground-Nesting Bees

3.1 Construction

Creating an area for ground-nesting bees to establish their nests can be very simple. The first step is to set aside a designated area for ground nesters that will be undisturbed (Vaughan & Black, 2007; Mader et. al., 2011). Choosing areas with minimal ground disturbance can still be detrimental to populations of bees nesting underground because the larvae are susceptible to injury. These areas can still be effective, but fully undisturbed parcels of land will be most effective.

Choose a location with bare ground available when selecting an area to set aside for ground-nesting bees (Buchmann, 2002). Soil type is also vitally important. As mentioned previously. Establish a nesting site for bees in locations where there is plenty of sandy or sandy loam soils, as these are generally preferred over clay or highly organic soils by ground-nesting bees (F. Drummond, personal communication, March 2013). Sandy and sandy loam soils are preferred because they tend to drain well (Vaughan & Black, 2007), which minimizes water seepage remaining in the underground nests. Ground-nesting bees also prefer to burrow into bare soil or areas with only patchy vegetation and will generally steer clear of thick grassy areas. If bare ground is not readily available, a feasible alternative is to dig ditches or create nesting mounds to maximize the accessibility of bare soil to these insects (Mader et. al., 2011; Vaughan & Black, 2007).

One way to create a habitat for bees is to remove existing plant material and mulch the area (Mader et. al., 2011). Excess soil from drainage ditches or silt traps can also be used to build small mounds. If building a mound it is important to make sure that the soil is well drained and in an open, sunny area (Shepherd, 2008). Any type of soil can be used as long as it is kept free of weeds or has only scarce vegetation. If necessary, sand or loam can be added to the soil to increase attractiveness to bees (Shepherd, 2008). It can also be beneficial to place some rocks in the area for bees to use as places to bask in the sun (Mader et. al., 2011).

3.2 Maintenance

Maintenance is easy and minimal for ground-nesting bees. First, it is important to keep deep ground disturbance to a minimum or avoided altogether in nest areas (Mader et. al., 2011). Also, provide full and direct sun exposure for the nests (Mader et. al., 2011). Bees rely on the sun to warm their bodies in the morning and maintain internal temperatures while underground; this is vitally important for ground-nesting bees. Close mowing can control vegetation encroachment in areas designated for ground nesters (Mader et. al., 2011). This will keep bare ground available for bees to create new nests, maintain good levels of sunlight for those nests, and will have limited effects on underground nests.

4. Bumble Bees

4.1 Artificial Nest Sites

The use of bumble bee nest boxes in North America is essentially nonexistent (S. Droege, personal communication, March 2013), and have only been successful in 20 percent of the cases where they are implemented (Mader et. al., 2011). The following two alternatives may be more beneficial to try before creating a wooden nest box.

1. Allow grassy areas to become dense and tall to the point where the grass falls over. This habitat is perfect because it is covered, warm, and dry (Mader et. al., 2011). Native bumble bees are likely to inhabit places such as old rodent nests or similar environments (National Research Council, 2007). In the Northeast, *Bombus* queens purposefully seek out old rodent nests because the physical structure and smell of rodent urine in these cavities is especially appealing to them (F. Drummond, personal communication, March 2013). This type of habitat is most attractive near wood lots, hedgerows, or the edges of the forest (Mader et. al., 2011).
2. Create compact piles of brush or fieldstones to imitate the cave-like conditions described above. These structures do not need to be large, but should provide a dark, protected cavity for the queen to start a colony (Mader et. al., 2011). The size and shape is ultimately irrelevant; however, it is important that it be protected from the rain so that the colony does not get too cold and mold does not cause disease.

4.2 Location and Installation

When choosing a location for an artificial bumble bee nest, it is important to look for a place that is away from human activity. By nature bumble bees are not hostile and it is safe to approach a nest. However, if a nest is placed too close to constant human activity they may feel continually threatened and become more aggressive (Mader et. al., 2011). It is recommended to place these nests at least 10 feet away from paths, patios, play areas, and other locations where people are highly active (Mader et. al., 2011). It is also helpful to establish a nest where there is limited to no risk of flooding (Shepherd, 2008).

It is best to install these nests in late winter or early spring; a good indicator is around the time of willow blooms (Mader et. al., 2011). This is because queens are ready to emerge and will be looking for a new place to start a colony. If bumble bee boxes are installed too late they may not be occupied at all during the season.

4.3 Wooden Nest Box Construction

Bumble bees prefer cavities with dimensions that are roughly 7x7x7 inches (Shepherd, 2008). Use either preservative free lumber for a wooden nest or an appropriate-sized container.

When creating an artificial bumble bee box:

1. Make sure to drill multiple holes on the upper section of the side panels of the box near the roof for ventilation. These holes should be covered with some type of screen to prevent ants and other pests from entering the nest (Mader et. al., 2011).
    a. The material used is irrelevant, other than it must be able to withstand inclement weather conditions. The nest cannot get damp inside, or fungi and mold can grow, and the larvae can get too cold and die. In order to avoid a box getting too moist, place chicken wire on the bottom of the box to aid in ventilation of the bedding material (Mader et. al., 2011).

2. The entrance tunnel should be ¾ inch in diameter. It can be composed of plastic pipe or another type of tubing (Mader et. al., 2011).
    a. The entrance tube should be long enough that it is able to be partially buried and reappear roughly two feet from the box itself. Protect the entrance from water seepage either by digging a small hole at the entrance of the tube or using a rock that hangs over the tube entrance (Mader et. al., 2011). This will often make the entrance more appealing for a queen, as she is looking for a safe cave-like cavity.
3. Nesting materials used for the inside of the box should be soft and fluffy. Hamster cage bedding, dry straw, cut up yarn or string, or upholstery's cotton are all appropriate, however, it is important to note that cotton balls are not suitable for bumble bees (Shepherd, 2008; Mader et. al., 2011). As noted above, rodent urine is highly attractive to *Bombus* queens, so using old rodent bedding may be effective.
4. Place the box in a dry, undisturbed location. It should be at ground level, or slightly buried, as these conditions are most attractive to bumble bees.

4.4 Maintenance

Bumble bee boxes require very little maintenance. Any unoccupied boxes can be removed, cleaned, and stored until next season by mid-summer (Mader et. al., 2011). Boxes that are not inhabited by a colony by this time are not vital to the overall population. For boxes that have been occupied, it is important to remove and clean the boxes when the season ends (Mader et. al., 2011). The queen will find a suitable place to overwinter, and the rest of the colony will die off. At this time, clean the box with a mild bleach solution to kill any parasites or disease that the previous colony has left behind (Mader et. al., 2011). It is also important to provide new nesting materials each season (Mader et. al., 2011). Reusing these materials will likely spread disease and cause populations to decline.

RHODE ISLAND NON-BEE POLLINATORS

1. Butterflies and Moths

1.1 Foraging

Butterfly and moth habitat requirements are very similar to those of the bee species previously described. Areas that can be used to promote forage for butterflies and moths include the side of a building on property, the edge of a crop field, random patches, or even bee pastures. Unlike bees, butterflies and moths are very sporadic in their foraging patterns (Losey & Vaughan, 2006), so make a variety of plants available over a wide range of habitat. It is important to plant wildflowers or other native plants that can serve as food sources. Position flowering plants in full sun, but where they are protected from the wind (Ley, 2008). Butterflies also require a year-round food source since most species do not migrate. Butterflies will thrive where open areas, i.e., large stones or bare ground, are provided so that they can bask in the sun (Ley, 2008).

Similar to bees, butterflies require a water source to be readily available and nearby their food. If a water source is not available, place a bowl or bucket of water near the forage habitat as long as it is large enough to be seen and can host a large number of insects at one time (Mader et. al., 2011). If the water provided is deep, supply butterflies and other insects with small sticks or other materials that will float in the water on which they can perch. Another valid source of water for butterflies is moist soil, which also serves as a source of vital minerals (Ley, 2008).

There are some major differences between moths and butterflies. Moths tend to forage throughout the night. Being nocturnal allows these insects to forage the same flowers that butterflies and bees have visited during the day without physically competing for space. Generally these moths emerge to begin foraging during twilight and evening hours, so flowers that are open during these times will be more attractive to these species (Hawkinson, 2005).

Although most moth species are nocturnal, there are some diurnal species that are active throughout the day (Hawkinson, 2005). Unlike butterflies, these moths that forage throughout the day hover over the flowers they visit. Because of this, moths are often less picky about having an ample landing platform during forage (Hawkinson, 2005).

1.2 Food Preferences

Flowers that are bright colors, including shades of red, pink, and purple, are the most attractive to butterflies (Ley, 2008). Unlike butterflies, who look for colorful flowers, moths prefer flowers that are pale or white in color (Ley, 2008). Because these insects have such long tongues, butterflies and moths tend to visit flowers with ample amounts of deeply hidden nectar. Butterflies use color patterns on the petals as nectar guides to find the nectar, similar to bees (Ley, 2008). Butterflies and moths also prefer long tubular flowers that have a faint, fresh, and sweet scent with a wide landing platform (Ley, 2008). Butterflies and moths do not have the same ability to carry large amounts of pollen like bees do, because they only drink nectar (H. Ginsberg, personal communication, April 2013), so they prefer flowers with lesser amounts of pollen.

Pipevine Swallowtail
Photo by: Leslie Corcelli

1.3 Reproduction

Butterflies and moths do not nest but require specific host plants as a food source for their larvae and caterpillars, and as a location to lay eggs. Some larvae eat the stems of the host plant, while others eat the leaves. Either way, that specific food source must be available or they will not lay eggs and the young will die (Mader et al., 2011).

Typically, each species of butterfly has its own specific host plant of choice; however, there are a few common plants that are appealing to multiple butterfly species. Some examples of universal tree varieties include oak, cherry, sassafras, maple, and willow. Examples of other plant varieties are vetch and milk vetch, milkweed, clover varieties, wild lupine, and Baptesia tinctoria (wild indigo) (Mader et al., 2011; Clark, 2005). Although these are common hosts, it is still recommended to conduct additional research on individual butterfly species to find out what specific plants will attract the butterfly species of interest.

1.4 Overwintering

Some butterflies migrate long distances, but most actually overwinter in their native areas. Overwintering can occur during any stage of life for the butterfly or moth, but typically they are in a larval stage at this time. In addition to providing proper nesting and foraging habitat, moths and butterflies will need help in creating an overwintering site. Often times they will overwinter in tree cavities, behind loose bark, within evergreen foliage, or under logs and rocks (Mader et al., 2011).

If this type of habitat is sparse on site, it is possible to build a pile of logs or rocks as a substitute. The pile must be able to protect the insects from heavy wind and precipitation throughout the winter (Mader et al., 2011). An easy way to do this is by making sure the logs are crisscrossed with gaps of 3 to 4 inches (Mader et al., 2011). This promotes a safe warm cavity for the butterflies to use during the winter. If aesthetics of this type of structure are an issue throughout the spring and summer months, plant nectar producing flowers around it, or plant a vine to grow over it.

Preserving an overwintering site requires some minor maintenance; including replacement of logs once they have rotted, or pruning back a vine that is growing over it (Mader et al., 2011). This is crucial to prevent the spread of mold and disease within the mound, and to prevent the vine from invading the mound and forcing the moths or butterflies out. It is best to do this maintenance during the summer months when the butterflies are not enclosed or exposed to excess harm. These are easy, efficient ways to create a balanced habitat for moths and butterflies that are overwintering.

2. Beetles and Flies

Although there are many beetle and fly species that pollinate plants and crops, they are not as particular in their foraging as other pollinators. Both beetles and flies will forage the same flowers and crops as bees.

Habitats for bees and butterflies will also likely cater to the egg-laying needs of all beetle pollinators (Mader et. al., 2011). Preferred nesting sites for beetle adults include snags, pre-existing cavities, dead wood, and stems of host plants.

Drone Fly
Photo By: Dann Thomb

Fly larvae have more specific requirements than do adults; however, habitat for bees and butterflies will again cater to the needs of flies. Fly larvae can be parasites of ground-nesting bees, and are also found living in dead wood, snags, and the bottom of bumble bee nests (Mader et. al., 2011). Larvae tend to prey on spiders and aphids, which are typically abundant in foraging habitats for bees and butterflies. Similar to beetles, fly habitat requirements can usually be met if bee and butterfly populations are satisfied.

3. Hummingbirds (Archilochus colubris)

3.1 Nesting Habitat

The Ruby-throated hummingbird is the largest animal pollinator found in Rhode Island. Their requirements are very different than insect pollinators; however, they are relatively easy to fulfill. These birds are very adaptive and have been found living in grasslands, open woodlands, forests, gardens, meadows, and backyards (Cornell Lab of Ornithology, 2009). According to the Cornell Lab of Ornithology (2009), females tend to build their nests on slender branches of deciduous trees, such as oak, hornbeam, birch, poplar, or hackberry, and are generally found 10 to 40 feet above ground level. Although these birds do pollinate in Rhode Island and other parts of New England, they do not commonly pollinate food crops (S. Droege, personal communication, March 2013). It is more common that these birds help to pollinate garden and backyard flowers.

3.2 Food Preferences

Two easy ways to feed and attract hummingbirds are to set up feeders filled with sugar water around one's property or to plant some of the many flowers that attract these birds. Hummingbirds prefer tubular-shaped flowers with ample amounts of nectar deeply hidden within them (Ley, 2008). Flower colors that are shades of white, orange, yellow and scarlet red are ideal (Cornell Lab of Ornithology, 2009; Ley, 2008). While preferred, these are not requirements. Hummingbirds can be found visiting other flowers that have only one or some of these traits. Some examples of plants attractive to hummingbirds include bee balm varieties, wild bergamot (*Monarda fistulosa*), cardinal flower (*Lobelia cardinalis*), fuchsia, columbine, foxglove, geranium, and many others (Winter, 2010; WHC & NRCS WHMI, 1999; Coverstone et. al., 2002). Ruby-throated hummingbirds travel south for the winter, requiring food sources into the early fall to provide energy for their upcoming migration.

Female Ruby-throated hummingbird drinking nectar
Photo by: Dick Daniels

In addition to enjoying nectar from flowers, Ruby-throated hummingbirds also feed on small insects, such as flies, mosquitoes, gnats, and other critters, including caterpillars, spiders and aphids (WHC & NRCS WHMI, 1999).

CONSIDERATIONS OF AGRICULTURAL BEST MANAGEMENT PRACTICES FOR PROMOTING POLLINATOR POPULATIONS

1. Pesticides

1.1 Toxicity

Pesticides are a consistent problem and growing concern for pollinators across the country. Each chemical has its own toxic effect on bees and other pollinators, and every species of bee or pollinator will react differently to them. There have been many studies on the effects of pesticides on honey bees, but almost no experiments have been conducted to see actual effects on native bee populations (Winfree, 2010).

Pesticides have both lethal and sub-lethal effects on bees and other pollinators, including the inability to return to a nest, impairment of foraging and obstruction to learning abilities, and delays in larval development (Roulston & Goodell, 2011). Mortality in honey bee colonies, as well as major declines in native species, is caused by this type of bee poisoning. There are many ways to avoid bee poisoning, including the recommendations provided in section 1.3 below.

One reason pesticides are harmful to honey bees is that the chemicals in pesticides hinder their ability to dance and communicate the location of pollen and nectar sources to others in the colony (Thompson, 2003). Additionally, it thwarts the ability of honey bees, as well as bumble bees, to return to the nest after pollen collection (Roulston & Goodell, 2011; Thompson, 2003). Another impact that pesticides, specifically herbicides, have on bees is that they can eliminate much of the forage that would otherwise be available as an alternative food source (Johansen, 1977; Roulston & Goodell, 2011). The sudden elimination of floral resources greatly decreases the amount of forage supply bees and other pollinators can visit. This is sometimes a problem with the cultivation of GMO crops. Depending on what resistance the GMO crop contains, the proteins can be sub-lethal for many bees (Winfree, 2010). Pest resistant GMO crops can also be harmful to bees if the protein that makes them resistant is present in the pollen or toxic to bees (Winfree, 2010). Also, if crops are pest resistant they may require lesser amounts of insectides; however, they may call for more intense applications of herbicides to control weeds.

1.2 Alternatives

Finding alternatives to pesticide use on a farm can be challenging depending on lot size and what crops are grown and produced on site. Many large-scale operations producing orchard fruits and legumes, such as apples, peas, or beans, tend to apply large amounts of pesticides (Ghazoul, 2005). The following are a few recommendations for potential pesticide substitutes on both large and small farms.

The following are feasible on smaller areas due to labor and time constraints:

1. Handpick or crush larger insects, as a definitive and productive way to ensure the mortality of pests (Mader et. al., 2011).
2. Spraying soapy water on smaller pests is generally just as effective as spraying harsh chemicals.
3. Fully remove infected leaves or shoots and vegetative debris from the previous crop (Mader et. al., 2011). This ensures that potential sources of infection or spread of disease are ultimately eliminated from the current crop.
4. In some cases spot treatments are effective in removing some pests (RI DEM, n.d.).

There following are alternatives for larger landscapes:

1. Install a protective barrier, e.g., floating fabric cover or a fence, while flowers are not in bloom. This allows plants to remain protected during their most vulnerable growing periods, while permitting pollinators to be present during crop bloom (Mader et. al., 2011).
2. Maximize crop diversity on site and to practice crop rotation whenever possible (Mader et. al., 2011). This is not only beneficial in keeping pests to a minimum, but is also favorable for soil health and fertility. Soils can be depleted of essential nutrients over time if the same crop is grown year after year on the same parcel of land. Ultimately, crop rotation will aid in the reduction of fertilizer use as soils become healthier.
3. Use sticky traps, pheromone traps, etc., to distract or stop pests from reproducing and spreading to new areas (Mader et. al., 2011).
4. Practice Integrated Pest Management (IPM) whenever possible (Mader et. al., 2011).
5. Provide pollinator habitats and encourage the growth of native plant species will also typically promote the population growth of natural crop pest predators (Vaughan et. al., 2009).

6. Use cover crops, such as clover and other legumes, as a pesticide alternative. Cover crops can be beneficial because they can serve as nesting locations for bees, especially *Bombus* queens, and can also aid in fixing nitrogen levels in the soil (Winfree, 2010).

1.3 Guidelines for Use

Application conditions can have a significant impact on bee species. If pesticide use is unavoidable, then the following suggestions should help reduce pesticide toxicity on bees. Often times, even with highly toxic pesticides, the toxicity effects can be minimized with proper use of the chemical (Cooley et. al., 2012).

1. Avoid application when flowers are in bloom (Cooley et. al., 2012). If applied when flowers are not in bloom, pollinators will not directly ingest the chemicals from pollen and nectar sources (Mader et. al., 2011). Although adult bees may be safe, keep in mind that some butterflies or other larvae may still be present and affected by the chemicals. It is also important to know that if spraying closed blooms, bees and other pollinators can still come in contact with pesticide residues once the flowers reopen, so this is equally as dangerous as spraying when flowers are open (F. Drummond, personal communication, March 2013).
2. It is best to spray in the early morning or late evening when pollinators are resting or sleeping (Mader et. al., 2011; Cooley et. al., 2012). If pollinators are less active at the time of application it is more likely that they will avoid direct contact with the chemicals until many hours after the application is over. Depending on the residual behavior of a pesticide, this can greatly reduce the toxicity to bees and other pollinators. If a pesticide has minimal effects when dry, this can be an effective method for pollinator protection (F. Drummond, personal communication, March 2013). Insecticides, however, are generally still dangerous to pollinators even many hours or days after the time of application.
3. It is best to apply when dry conditions are present (Mader et. al., 2011). Moisture and wetness can increase toxicity of many chemicals to bees.
4. Wind can play a major factor in application timing and toxicity. Spray when winds are minimal. Wind increases pesticide drift, which can be detrimental to bee nesting and foraging sites (Mader et. al., 2011). Additionally, pesticides that produce smaller droplets are more likely to be susceptible to causing harm through drift (Vaughan et. al., 2009).
5. It is important to read chemical instructions before use, and to use the minimum recommended dose as instructed on the chemical label (Cooley et. al., 2012; Mader et. al., 2011).
6. Be aware of neighboring properties. Home gardens can be more harmful per acre than agricultural fields in terms of chemical toxicity to insects (Mader et. al., 2011). Homeowners typically apply chemicals in higher doses than recommended, so it is beneficial to know when homeowners own adjacent land (Mader et. al., 2011). Their actions may unfortunately have negative effects on those pollinators.
7. Be careful in choosing what form of pesticide to use. Dust and powder formulas are generally more toxic to bees and other pollinators than some sprays (Vaughan et. al., 2009; Johansen, 1977).
8. Sprayers need to be properly calibrated before use (Vaughan et. al., 2009), and should be calibrated often to insure the accuracy of application.

1.4 Organic Pesticides

It is important to note that organic pesticides can still be harmful to pollinators (Mader et. al., 2011). A few basic examples are Rotenone, pyrethrin, and spinosad. These are organic broad-spectrum insect killers, meaning they eradicate both pests and other potentially beneficial species alike, including pollinators (Mader et. al., 2011; D. Gregg, personal communication, March 2013). Some possible pesticide alternatives that are organic yet less toxic to bees include horticultural oils and insecticidal soaps (Mader et. al., 2011).

2. Mowing

2.1 Disadvantages

Mowing can unfortunately be dangerous to pollinator populations. Mowing destroys habitat for any bees or other pollinators which use tall grasses and weeded areas for nesting, egg-laying, or foraging. It abruptly removes flowers that could be used as forage and removes height variability, which otherwise encourages a variety of pollinators to utilize that area (Mader et. al., 2011). It can also directly kill many pollinating insects, especially those in the egg or larval stages. If mowing as part of a pollinator habitat management system, no more than 25-33% of the area should be mowed at any given time, and should typically be done in the winter months (Vaughan et. al., 2009). This will ensure the protection of overwintering or sheltered pollinators.

2.2 Alternatives

There are many potential alternatives to mowing that avoid destruction of pollinator populations.

1. Allow livestock to graze rather than machine mowing an area with a machine. If implemented properly, grazing can have a positive effect both on the land and pollinators. Additional information concerning grazing is discussed in Section 4 below.
2. Permit unused parcels of land to grow weeds and other native plants. This can encourage butterflies, moths, bees and other pollinators to lay eggs, build nests, and forage without disturbance rather than in areas with frequent mowing routines (Mader et. al., 2011; National Research Council, 2007). This also promotes height variability and a consistent, year-long food supply, ultimately attracting a larger number of pollinators to that area. Periodic mowing may still be necessary to prevent habitat succession and to keep out woody plants and non-native, invasive shrubs, such as autumn olive or shrub honeysuckle (D. Gregg, personal communication, March 2013).

An un-mown field with wildflowers for forage and a diverse grassy landscape for pollinator nests
Photo by: Alan Howes

Consider a combination of timing, technique, and scale to dictate how, when, and where mowing occurs.

1. Use a flushing bar.
2. Mow at decreased speeds (somewhere at or below 8mph).
3. Increase the mow height when possible (Mader et. al., 2011). A height between 12 to 16 inches allows for the greatest plant variation, encouraging all pollinator life stages to be present (Mader et. al., 2011).
4. Mowing in patches, if possible, will allow populations of pollinators to recover from a mowing event, as they can move from the destroyed area to the untouched patches (Mader et. al., 2011).
5. Decrease the devastation of mowing by avoiding mowing at night or at times when the bees and other pollinators are asleep. This can increase a pollinator's ability to abandon the site during mowing and decreases the chance of direct insect mortality (Mader et. al., 2011).
6. Do not mow out to the farm's property line. If a strip of land is left between crop fields, buildings, and the property line, then pollinators will strive to nest and forage in those areas, eventually increasing populations on site. It can be difficult to manage these weedy borders because a balance is needed to prevent encroachment and growth of invasive, aggressive woody plants, while minimizing mowing activity. Implement a strict and active management plan to prevent the aforementioned plants from becoming dominant in these habitats.

3. Tilling

Similar to mowing, tilling can be difficult to avoid but is also harmful to pollinators. Tilling is the process of overturning the top soil on a particular plot of land where crops were grown the previous season and is typically implemented on an annual or semiannual basis (Roulston & Goodell, 2011). There are many different machines and tools used to till a parcel of land and each of these will have its own species specific effects on bees and other pollinators in the surrounding environment (Roulston & Goodell, 2011).

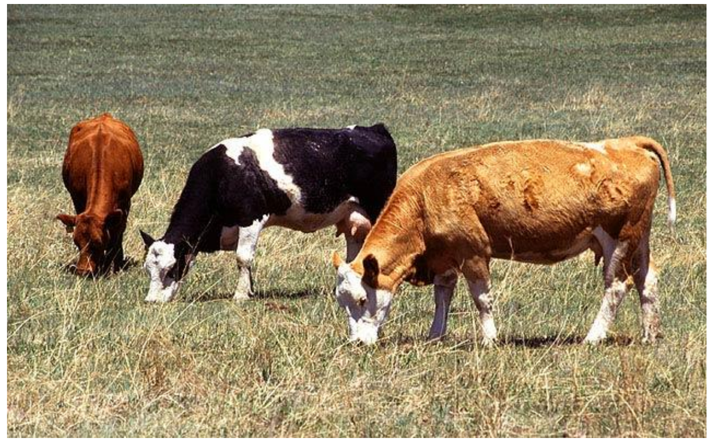
The only two true alternatives to tilling practices are no-till or limited-till management. These can be difficult for large scale farms, but could be tested on smaller plots within a large farm. It is especially important to try less invasive or destructive procedures in sections where ground-nesting bees are likely to live and thrive (Mader et. al., 2011). This includes areas where cucurbits are grown since squash bees (*Peponapis pruinosa*) build their nests near the base of these plants. Insects, such as bees or beetles, which overwinter in their subterranean nests, are generally more susceptible to mortality due to tilling practices than other insects. The depth of these nests will indicate how susceptible each species is to direct mortality (Roulston & Goodell, 2011). Farms which practice no-till agriculture on cucurbit crops tend to have squash bee populations three times as large as farms that use tilling practices (National Research Council, 2007). However, Julier & Roulston (2009) found that *P. pruinosa* can live on properties that do implement tillage as a farm management practice, which is attributed to their philopatric tendencies.

Although no-till or limited-till methods are ideal, they do have some consequences. According to R. Brown (personal communication, October 2012), Associate Professor in the Department of Plant Sciences and Entomology at the University of Rhode Island, it can be difficult to control weeds without using herbicides in no-till systems. Crops may grow more slowly in no-till or limited-till systems, which can be problematic for people trying to market their products (R. Brown, personal communication, October 2012).

4. Grazing

4.1 Disadvantages

For farms that use grazing livestock as an alternative to mowing, there are some precautions that should be used. If not managed properly, grazing can cause significant damage to pollinator populations and the surrounding environment. Historically, grazing has been shown to have detrimental ecological effects, though its direct effects on insects are not very well known (Fleischner, 1994). However, according to Mader et. al. (2011), when there is an increased grazing intensity, pollinators become more scarce. This can be due to insufficient forage supply, destruction of nesting habitats, or even direct trampling of adults (Mader et. al., 2011).



Grazing Cattle
Photo by: Scott Bauer

Allowing livestock to graze can be harmful to pollinators. Similar to mowing, there should be no more than 25 to 33 percent of an area serving as pollinator habitat to be grazed at one time (Vaughan et. al., 2009). Pollinators need sufficient forage throughout the year, and if animals are allowed to eat the few flowers left then there will be an insufficient food supply for the pollinators (Mader et. al., 2011). Often times, intense grazing naturally reduces the abundance of flowers present in that given area (Mayer, 2007). Research has shown that intense grazing can deplete plant diversity and the availability of flowers for forage as well as nesting sites for pollinators (Kearns & Inouye, 1997). Ground nests can be destroyed through trampling from livestock (Kearns & Inouye, 1997).

Also, intense grazing can cause soils to become highly compact (Fleischner, 1994), which can be less attractive to some ground-nesting bees. Grazing also has the ability to encourage weed or invasive species encroachment (Fleischner, 1994). This intrusion can force wildflowers and other native plants to disappear or decrease in abundance, ultimately diminishing the amount of food available for foraging pollinators.

4.2 Grazing Advantages

In spite of these disadvantages, well-managed grazing can be an effective and beneficial way to increase pollinators on a farm. Utilizing manageable levels of rotational grazing throughout pastures or unused plots can help maintain open, blossoming plant communities that support a diversity of butterfly, bee, and other pollinator populations (Mader et. al., 2011). These open areas can be used for foraging habitats for pollinators as an alternative to creating a new foraging environment. This type of grazing is also an encouraging alternative to mowing any unused parcels of land on site.

CONCLUSION

Pollinator populations have been declining for decades, especially bumble bees and honey bees, which is a growing concern for the agriculture industry. Pollination services provided by managed and native species are vital to producers, because without pollination services, crop yield, size, and quality will all decline. In an attempt to address the declining population issue, the RI NRCS and the Heinz Center have generated this report for Rhode Island producers and constituents.

The Heinz Center and the Rhode Island NRCS hope that this document provides useful tips and guidelines for those who wish to promote pollinator population health and growth in Rhode Island. This document provides essential information about pollinators found in Rhode Island and their respective habitat requirements in an attempt to increase basic knowledge of these topics throughout the state. It is to be used as a tool for Rhode Island conservation practitioners to better understand the relationships between pollinators and agricultural practices. Please contact the Rhode Island NRCS office in Warwick at (401) 828-1300 for information on technical and financial assistance for pollinator habitat management.

APPENDIX

Table 1. Common Rhode Island Bee Genera

Common Rhode Island Bees		
Common Name	**Family**	**Genus**
Bumble	*Apidae*	*Bombus*
Carpenter	*Apidae*	*Xylocopa*
Honey bee	*Apidae*	*Apis (mellifera)*
Mason	*Megachilidae*	*Osmia*
Mining	*Andrenidae*	*Andrena*
Squash	*Apidae*	*Peponapis, Xenoglossa*
Sweat	*Halictidae*	*Halictus, Lasioglossum, Augochlorella*

Table 1. Display of common bee species found in Rhode Island with both common and scientific names. Note that this chart is not inclusive of every genus found in the state, but highlights the most common bees.

Table 2. Recommended Bee Densities for Maximum Pollination Services

Recommended Bee Densities			
Crop	**# *A. mellifera* colonies per acre**	**# *B. impatiens* colonies per acre**	**Other Notes**
Apple	1.5	2-4	250 *O. lignaria*/acre 1 honey bee per 1000 flowers *B. impatiens* - variety dependent stock rate
Blueberry	3	2-4	~250 individuals per *Bombus* colony
Cranberry	3	3	443 *Bombus* per acre
Cucumber	2.2	2*	1 honey bee per 100 flowers
Peach	0.8	---	
Raspberry	0.8	3	1 honey bee per 100 flowers
Squash/pumpkin/gourd	1.5	2*	1 *Peponapis* per 20 flowers *Bombus* rate determined from 4 colonies per 2 acre ratio
Strawberry	3.5	---	1 *A. mellifera* colony per 10,800 ft^2 of glasshouse
Tomato	---	3-8	Both rates are specific to greenhouse tomatoes. *B. impatiens* rate is variety dependent and is measured per acre per month
Watermelon	1.8	2*	1 honey bee per 100 flowers
Additional Note: *It is recommended that sugar water bladders are removed from hives highlighted with an asterisk (*). All recommended tock rates for B. impatiens are appropriate with or without the presence of other pollinating species (Biobest, personal communication, April 2013)*			

Table 2. Bee densities are derived from both literature and calculation. The numbers represent densities of honey bees and commercial bumble bees per acre. The conversion rate used for calculations is 1 acre = 0.4 ha. Some *B. impatiens* data is unavailable due to a lack of literature and/or scientific support. References used: Loose (2005), Abrol (2012), Delaplane et. al. (2010), Bosch (2002), Richards & Kevan (2002), Stubbs et. al. (2002), Drummond (2012), Morandin (2000), Petersen & Nault (2013). Stubbs & Drummond (2001), Biobest (personal communication, April 2013).

Table 3. Native Pollinator Habitat Requirements

Native Pollinator General Habitat Requirements		
Pollinator	**Forage/Food**	**Shelter/Nesting**
Bees	Pollen & nectar; typically blue, violet and yellow pigmented, shallow flowers	near food and water; adequate sun exposure g*round:* bare or patchy soil; well-drained soils; full sun t*unnel/cavity:* nest boxes; dead wood, snags, old beetle tunnels; soft woods preferred over hardwoods; hollow plant stems; morning sunlight b*umble:* bunch grasses; old rodent nests; nest box; large dry cavity protected from weather and wind
Butterflies	*Egg:* not feeding *Caterpillar:* leaves, stems, flowers of host plants *Pupa:* not feeding *Adult:* nectar, rotting fruit, etc; typically bright colored, tubular flowers	on or near larval host plants *overwintering:* dry, protected cavity that shelters against weather and wind
Moths	*Egg:* not feeding *Caterpillar:* leaves, stems, flowers of host plants *Pupa:* not feeding *Adult:* nectar, rotting fruit, etc; typically bright colored, tubular flowers	on or near larval host plants *overwintering:* dry, protected cavity that shelters against weather and wind
Beetles	host plants; insects; nectar; pollen; spiders	dead wood; snags; pre-existing cavities; on or near larval host plants
Flies	insects; spiders; aphids; nectar; typically white, pale colored flowers	dead wood; snags; old beetle/bee cavities; bottom of bee nests, i.e. bumble & ground nesters; on or near larval host plants
Hummingbirds	nectar; insects; spiders; caterpillars; aphids; tree sap; typically red pigmented, tubular flowers	tall mature trees

Table 3. Includes general information regarding native pollinator groups and their respective habitat requirements.

Table 4. Native Plants Suggested for Pollinator Habitats

Native Plants for Pollinators		
Common Name	**Latin Name**	**Seasonal Bloom Period**
Bicknell's cranesbill	*Geranium bicknellii*	Spring
Blue wild indigo	*Baptisia australis*	Spring (very early)
Butterfly milkweed	*Asclepias tuberosa*	Summer
Canada goldenrod	*Solidago canadensis*	Autumn
Cardinal flower	*Lobelia cardinalis*	Summer/Autumn
Cranesbill (Geranium)	*Geranium spp.*	Spring/Summer
Goldenrod	*Solidago spp.*	Autumn
Joe-Pye weed	*Eupatorium fistulosum*	Summer
Milkweed	*Asclepias spp.*	Summer
Mountain mint	*Pycnanthemum muticum*	Summer
New England aster	*Symphyotrichum novae-angliae*	Autumn
New York aster	*Symphyotrichum novi-belgii*	Autumn
New York ironweed	*Vernonia noveboracensis*	Autumn
Purple giant hyssop	*Agastache scrophularifolia*	Summer
Red honeysuckle	*Lonicera sempervirens*	Spring/Summer
Wild bergamot	*Monarda fistulosa*	Summer
Wild lupine	*Lupinus perrenis*	Spring
Trees & Shrubs		
American basswood	*Tilia americana*	Spring/Summer
Common serviceberry	*Amelanchier arborea*	Spring
Highbush blueberry	*Vaccinium corymbosum*	Spring
Meadowsweet	*Spirea latifolia*	Summer
Pussywillow	*Salix discolor*	Spring (very early)
Steeplebush	*Spirea tomentosa*	Summer

Table 4. An outline of native plant species in the Northeast that pollinators can utilize as forage. The chart is designed to show bloom period and plant name in order for decisions to be made regarding choice of vegetation.

Table 5. Local Plant Selection Resources

Plant Selection Resources in Rhode Island	
Organization Name	**Contact Information**
RI Wild Plant Society (RIWPS)	***Phone:*** *(401) 789-7497* ***Email:*** *office@riwps.org* ***Website:*** *www.riwps.org*
RI Nursery and Landscape Association (RINLA)	***Phone:*** *(401) 874-5220* ***Email:*** *executivedirector@rinla.org* ***Website:*** *www.rinla.org*
Rhody Native	***Website:*** *www.rinhs.org/who-we-are-what-we-do/programs-projects/rhodynative/* *Rhody Native is managed by the RI Natural History Survey* ***Phone:*** *(401) 874-5800* ***Email:*** *info@rinhs.org* ***Website:*** *www.rinhs.org*
URI Master Gardeners	***Website:*** *www.urimastergardeners.org*
New England Wetland Plants, Inc.	***Phone:*** *(413) 548-8000* ***Email:*** *info@newp.com* ***Website:*** *www.newp.com*
The Xerces Society for Invertebrate Conservation	***Phone:*** (503) 232-6639 ***Email:*** info@xerces.org ***Website:*** www.xerces.org

Table 5. Indicates a selection of resources for advice and recommendations of potential plants to utilize in enhancement of created bee habitats. This list is not inclusive of all options available throughout Rhode Island or New England, but rather highlights a select few.

Table 6. Purchasing Resources for Pollinator-friendly and Wildflower Seed Mixes

Where to Purchase Seed Mixes		
Organization	**Contact Information**	**Website**
Ernst Conservation Seed	***Phone***: (800) 873-3321 ***Email***: sales@ernstseed.com	http://www.ernstseed.com/seed-mixes/
New England Wetland Plants, Inc.	***Phone***: (413) 548-8000 ***Email***: info@newp.com	http://www.newp.com/catalogue-seeds.html
Seedland	***Phone***: (386) 963-2080 ***Email***: sales@seedland.com	http://www.wildflowermix.com/
Hancock Seed Company	***Phone***: (800) 552-1027	http://www.hancockseed.com/climate-zone-238/cool-climate-seed-122/wildflower-seed-mixtures-140/
BBBSeed	***Phone***: (303) 530-1222 ***Email***: info@bbbseed.com	http://www.bbbseed.com/store/wildflower-mixes/special-uses
Fiddlehead Creek	***Phone***: (518) 632-5505 ***Email***: emily@fiddleheadcreek.com	http://fiddleheadcreek.com/native-plant-nursery/plant-catalog/seed-mixes/
2B Seeds	***Phone***: (800) 833-5988 ***Email***: custserv@2bseeds.com	http://www.2bseeds.com/flowers-for-bees.shtml
Outsidepride.com	***Email***: support@outsidepride.com	www.outsidepride.com

Table 6. Indicates some resources to purchase pollinator-friendly and regional wildflower seed mixes. The list is not inclusive of all possible manufacturers, producers or resources, but can be used as a reference for such purchasing and consultation purposes.

Table 7. Consultation Resources for Artificial Nest Construction

Resources for Artificial Nest Construction	
Organization	**Contact Information**
RI Natural Resources Conservation Service (NRCS)	***Phone***: (401) 828-1300 ***Website***: www.nrcs.usda.gov/wps/portal/nrcs/site/ri/home/
US Department of Agriculture (USDA)	***Phone***: (202) 720-2791 ***Website***: usda.gov/wps/portal/usda/usdahome
Xerces Society	***Phone***: (855) 232-6639 ***Website***: www.xerces.org/
Pollinator Partnership	***Phone***: (415) 362-1137 ***Website***: www.pollinator.org/

Table 7. Short list of possible resources for consultation on the creation of artificial nest blocks and boxes. The list is not inclusive of all local or national resources available; additional research may be required.

Table 8. Local and Commercial Bees and Beekeeping Supplies

Local and Commercial Bees and Beekeeping Supplies		
Organization	**Contact Information**	**Location**
Aquidneck Honey	***Phone:*** (401) 862-2171 ***Email:*** jeff@aquidneckhoney.com ***Website***: www.aquidneckhoney.com	Middletown, RI
Wood's Beekeeping Supply and Academy	***Phone***: (401) 305-2355 ***Email***: info@woodsbees.com ***Website***: www.woodsbees.com	Lincoln, RI
Hansen Apiaries, LLC	***Phone***: (860) 455-2288 ***Email***: hansenapiaries@charter.net ***Website***: www.hansenapiaries.net	Eastern CT
Crystal Bee Supply	***Phone***: (978) 535-1622 ***Email***: joegaglione@crystalbeesupply.com ***Website***: www.crystalbeesupply.com	Peabody, MA
Lagrant's Beekeeping Supplies	***Phone***: (413) 967-5064 ***Email***: Frank@LagrantsHoneybees.com ***Website***: www.lagrantshoneybees.com	Ware, MA
New England Beekeeping Supplies, Inc.	***Phone***: (978) 957-2233 ***Email***: rick@nebees.com ***Website***: www.nebees.com	Tyngsboro, MA
Biobest	***Phone***: (661) 792-6810 (California Office) ***Email***: info@biobest.be ***Website***: www.biobest.be	International/California, USA
Koppert Biological Systems	***Phone***: (810) 632-8750 ***Email***: asktheexpert@koppertonline.com ***Website***: www.koppert.com	International/Michigan, USA

Table 8. Includes a list of potential resources for beekeeping supplies and commercial bees. This is not inclusive of all local or national producers, but can be used as a guide for further research.

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