

Bumblebee Pollination in Central North Carolina:
Conservation Through Land Management and Education

by

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Abstract

For the first time, *Bombus* pollination activity was studied from a land management perspective using field surveys on managed properties in the Uwharries region of central North Carolina. Summer bumblebee populations were compared for three sites that differed in their management practices. Practices included combinations of prescribed burns, mowing, herbicide treatment, and planting vegetation to maintain open habitat. Surveys of *Bombus* pollination visits were supplemented by morphometric measurements of captured bees to assess bumblebee colony health. Only two common species of *Bombus* were found. Abundance and abundance per forage unit were greatest at the recently burned field site, suggesting that this site's land management practices were most supportive of bumblebee populations. Bumblebee size did not differ significantly between sites. Abundance and diversity was low across all the sites, possibly due to daytime temperatures above many species' optimal thermal range. Land management strategies are recommended for improving bumblebee conservation in the region. Citizen science and other educational initiatives are also encouraged to promote conservation.

Introduction

The conservation of pollinating insects is an important consideration for land managers, and for the public at large. Many pollinating insects, including native bumblebees, are facing serious declines (Cameron, Lozier et al. 2011), while agriculture becomes increasingly dependent on their services (Klein et al. 2007). Pollination by bumblebees is also vital for native ecosystems (Hellgren, Vaughan et al. 1989). Bumblebee conservation protects these services and offers excellent opportunities for citizen science, with benefits for both ecology and education.

This project focuses on *Bombus spp.* (bumblebees), the apex pollinator for many North American ecosystems (Mader, Shepherd et al. 2011). Research for this project was conducted in collaboration with the LandTrust for Central North Carolina (LTCNC, or “the LandTrust”) in the Uwharries region of Piedmont (central) North Carolina in June and July, 2011. Detailed population information is urgently needed to guide native pollinator conservation in the Uwharries and across the continent. Understanding bumblebee habitat needs can guide land management decisions and improve practical implementation of pollination conservation best management practices. Field surveys of bumblebees and literature review inform comprehensive recommendations for improving pollinator conservation in the region. Environmental education materials are a vital stepping-stone to public awareness of these issues in the Uwharries, fueling local support for conservation initiatives. Finally, this research will be an important starting point for accelerating scientific study of bumblebees and other native pollinators in central North Carolina.

The Importance of Pollinators

Pollination is important for plant reproduction because it provides a method for plants to transfer male gametes (reproductive cells) in pollen to the ovary in flowers for the fertilization that creates new seeds. Fruit develops around seeds, so fertilization is also necessary for fruit production. Many of the foods we eat are derived from plant seeds (e.g. wheat, barley, nuts), fruits (e.g., tomatoes, avocados), or even flowers (e.g. broccoli, artichokes). Different plants rely on different vectors to transfer pollen in sexual reproduction, including wind, water, or animal vectors, including insects. Thirty-five

percent of food crops worldwide by volume are pollinated by insects (Klein, Vaissière et al. 2007). Bees are thought to have co-evolved with flowering plants during the early Cretaceous period (Danforth 2007). The plants provide food for the bees while bees provide the plants with an effective means of reproduction. Many plants have evolved dedicated forms in flowers that are shaped, colored, and scented to attract bees. The pollen and nectar also represent a reward of calories that the plant loses in order to feed the bees well. Many bees have simultaneously evolved to effectively transfer pollen in their hairs from flower to flower of each plant species (Danforth 2007).

In a review of crops' from 200 countries, Klein, Vaissière et al. (2007) found that 87 leading global food crops rely on animal pollination versus just 28 crops that do not, representing the majority of the diversity of our important food plants. The vast majority of animal-mediated pollen transfer is by bees, of which there are more than 16,000 described species (Danforth 2007). We rely on bees to pollinate fruits, vegetables, and forage crops (Krombein 2008). Economically important crops pollinated by bees include apples, watermelon, pumpkins, squash, grapefruit, coffee, tomatoes, sunflowers, and many others. Bee-pollinated plants also help feed the animals we eat, such as cattle fed on alfalfa (Aizen, Garibaldi et al. 2009).

Native pollinators are considered a natural resource due to their pollination services, estimated to provide up to \$200 billion of services worldwide (Klein, Vaissière et al. 2007). In 2003 the value of insect-pollinated crops in the US was estimated to be between \$18 and \$27 billion, with additional value for secondary products like alfalfa-fed beef (Mader, Shepherd et al. 2011). Native insects' wild pollination services are estimated to be responsible for about 15% percent of this value, contributing around \$3 billion of value to the overall United States economy (Danforth 2007). Cultivated bees, including honeybees and more recently cultivated bumblebees, are already highly valued for their pollination services. For example, one study found that, "in 2004, 99,000 acres of greenhouse tomato production were pollinated worldwide by bumblebees, with an estimated value of approximately \$15 billion," (Winter, Adams et al. 2006). Although honeybees provide the majority of US commercial pollination services, cultivated and native bumblebees are important economically and ecologically for agricultural and natural ecosystems (Mader, Shepherd et al. 2011).

Bee pollination is also critical for the function of food webs in natural ecosystems. For example, black bears and other wildlife rely on pollination for adequate food supply (Hellgren, Vaughan et al. 1989). Linking pollination services to broader conservation efforts, such as conservation of charismatic megafauna like bears, can be a useful approach for engaging the public in ecosystem-wide conservation efforts.

Insects shape the landscape by influencing the community composition of vegetation, but the landscape also shapes populations of insects (Klein, Vaissière et al. 2007; Quintero, Morales et al. 2010; Haaland, Naisbit et al. 2011). For example, intensively cultivated lands do not support enough wild pollinating insects to adequately pollinate the crops (Klein, Vaissière et al. 2007). The conservation of native pollinators is a global issue encompassing the industrial food system and development patterns across whole continents.

Individual communities can engage with conservation on more local scales. Pollination is important for landowners in the Uwharries, including the LandTrust and its affiliates who aim to enhance agricultural productivity, ecosystem health, or both. On properties that the LandTrust owns, knowledge of how prescribed burns, mowing, and vegetation restoration effect pollination can guide future management decisions. The LandTrust can also use information about relative pollination health on cultivated versus wild land to help examine the conservation value of farmlands. Pollination is an ecosystem service that is financially and ecologically valuable, yet it remains relatively unstudied in the Uwharries (Cockman 2011).

Bumblebee Diversity and Biology

Worldwide there are more than 1000 bee species of Apidae, the family of honeybees, bumblebees, and carpenter bees (Krombein 2008). The *Bombus* genus, bumblebees, includes more than 40 species in North America. Bumblebees are our most important native pollinator (Free 1970). As plant generalists they effectively pollinate a wide range of flowers (Free 1970). Familiar species in North Carolina include the Common Eastern Bumblebee (*Bombus impatiens*). Bumblebees are frequently noticed and relatively admired insects—even if the admirer doesn't know which kind of bee they are seeing. Bumblebees are commonly understood to be beneficial to gardens, many

people consider them harmless due to their reluctance to sting, and relative to many other invertebrates they are well-liked for being “fuzzy and cute.”

Like other wildlife, bumblebees require adequate habitat, food for energy, and freedom from toxins and disease for completing their life cycles. Each species is associated with a geographic range that incorporates climate-specific temperatures and other physiological characteristics to which it is adapted (Goulson 2010). Bumblebees are social insects, with new colonies forming each year from solo over-wintering queens born at the end of the previous warm season. The bumblebees nest and brood in ground-level cavities. Queens often rely on tussocks of grass and undisturbed abandoned rodent nests to build their tennis-ball-sized nests each spring, which she stocks with pollen before laying her first eggs. The queens mate in late fall before hibernating, and store the male bee semen in their bodies. Female workers are born from unfertilized eggs throughout the warm season. These closely-related sister bees gather pollen and nectar which they consume and bring back to the nest to help rear more young. The colony grows throughout the season. Individual workers live only a few weeks. The colony produces larger bees as it grows—both because more workers in the colony can provide more nourishment to developing young, and because floral resources often increase through the season. Near the end of the warm season, males and young queens are produced. They mate in the fall, then the colony dies except for new queens, which hibernate in shallow underground burrows through the winter to begin anew the following year (Goulson 2010).

Bumblebees’ abundance, physical characteristics, and behavior make them exceptional contributors to plant pollination (Winter, Adams et al. 2006). They are generalists, with a more diverse diet than specialist native bees that rely on fewer plant species. Bumblebees can sonicate, or “buzz pollinate”, certain flowers (notably those of the tomato plant) to extract copious amounts of pollen, making them up to 400 times more successful pollinators than honeybees for these plant species. Sonication produces a buzz pitched in middle C, and is possible because the bees can vibrate their flight muscles without flapping their wings; they do so while dangling from their jaws beneath the flower’s salt-shaker-like stamens to release the shower of pollen (Mader, Shepherd et al. 2011).

Due to their large size and dense pile, bumblebees are active in a wide range of climatic conditions, including colder regions and for a longer season than their relatives. They are most active between 10 and 32 °C (50 to 86 °F) and can fly in light rain (Winter, Adams et al. 2006).

Bumblebees are a good proxy for pollination services in general because they are active, generalist foragers nesting at ground level, which mimics the habitat needs of many other native bees (Mader, Shepherd et al. 2011). The comparison is not perfect: relatively large forage ranges compared with smaller native bees means bumblebees may have access to more resources than other bees. Floral specialists could be threatened where bumblebees survive on other flowers. And bumblebees' social behavior means they potentially contact more pesticides than solitary species. But the decline of bumblebees should serve as a warning that other species are likely threatened, and potentially are even more threatened than bumblebees. Bumblebees are easy to study, even with untrained citizen science volunteers, because they are relatively abundant, large, and recognizable (Mader, Shepherd et al. 2011). They share similar enough habitat and foraging requirements with other pollinators like solitary native bees that assessing bumblebee pollination is a good first step toward overall pollinator conservation in the Uwharries.

Bumblebees in Decline

Pollinating insects of North America—including native bees and introduced honeybees—have faced heavy declines in recent decades, matching similar global trends (Cameron, Lozier et al. 2011). Many native bee species are significantly threatened (Kearns, Inouye et al. 1998; Mader, Shepherd et al. 2011), and some appear to have declined from healthy populations to extinction in the past few decades (The Xerces Society for Invertebrate Conservation 2011). Researchers studying tens of thousands of museum records and field specimens and found that bumblebees declined by up to 96% for some species with range decreases of 23 to 87% in the last 20 years (Cameron, Lozier et al. 2011). The yellow-banded bumblebee (*Bombus terricola*) dropped from its place as the most abundant bumblebee in Wisconsin to comprising less than 1 percent of its bumblebees between the mid-1990's and mid-2000's. Other bumblebee species recently

showing dramatic declines include the western bumblebee (*Bombus occidentalis*), Franklin's bumblebee (*Bombus franklini*, thought to be extinct), and the Rusty-Patched Bumblebee (*Bombus affinis*), (Mader, Shepherd et al. 2011). The historic range of the Rusty-Patched Bumblebee can be seen in Figure 1 to cover the majority of eastern North America, but this species has not been seen in recent surveys in several provinces and states where it once was common, including North Carolina (Colla and Packer 2008).



Figure 1. Historic range of the once-common *Bombus affinis* (Rusty-patched Bumblebee). The species was common throughout North Carolina as of 1971-1973 (The Xerces Society for Invertebrate Conservation 2011). It was rarely seen throughout its entire range in 2004-2006 (Colla and Packer 2008).

Many causes for pollinator declines have been proposed, and scientific studies frequently suggest that a combination of several threats has reduced the pollinators' numbers. Declines have been linked in part to land management practices (Pywell, Warman et al. 2006), fueling new interest in understanding the complex interactions between native pollinating insects and managed green spaces such as farms and nature preserves. In North America, threats from non-native pathogens may be more important than effects of land use change or pesticide use, but the contributions of different threats to declines have been difficult to quantify (Williams and Osborne 2009; Goulson, Rayner et al. 2011). In Europe, some range shifts and shrinking ranges indicate that climate change may be negatively affected bumblebees, though more research is needed to clarify these trends (Williams et al. 2007). A review of worldwide bumblebee research found that changing agricultural practices and policies are most often cited as the likely cause for bumblebee declines (Williams and Osborne 2009). Altered habitat interacts with

additional factors: one review notes that bumblebee species most threatened by land use changes are those with “small climatic ranges, range edges, and late-starting colony development cycles,” (Williams and Osborne 2009). Globally, competition from non-native bees is also an important threat, suggest reviewers (Goulson, Rayner et al. 2011). Reviews of threats recently focus on pesticides, especially the relatively new neonicotinoid chemicals (Blacquière, Smagghe et al. 2012; Hopwood, Vaughan et al. 2012). At-risk bumblebee species face more intense threats and have greater vulnerability to those threats as a species (Williams, Crone et al. 2010).

Bumblebees are affected by insecticides, habitat loss, degradation of nesting and foraging sites, and parasites and diseases (Claire 2002; Mader, Shepherd et al. 2011; Blacquière, Smagghe et al. 2012). These threats make them susceptible to changing land management practices in the Uwharries. Despite their declines, bumblebees will become increasingly important for natural and agricultural ecosystem health as threats to other native bees and to honeybees simultaneously increase (Kearns, Inouye et al. 1998).

Bumblebees seem to be immune to Colony Collapse Disorder, which severely reduced populations of the European honeybee globally (Mader, Shepherd et al. 2011). However, a fungus has recently been associated with declines of four once-common bumblebee species (Cameron, Lozier et al. 2011). Other bumblebee species studied were not in decline, and in fact some were increasing. These included the species relevant for this study: *Bombus impatiens* and *Bombus bimaculatus*, both of which now seem to have larger ranges compared to 20 years ago. The fungus associated with species in decline was found less often on specimens of these and other thriving species (Cameron, Lozier et al. 2011).

Pollination Conservation is Shaped By Land Management

Land use in central North Carolina is rapidly changing with conversion of hardwood forests and fallow fields to timbering operations, and commercial and residential development. Cities, towns and their suburbs can offer diverse forage for bees but pose unique threats. It is necessary to understand how management decisions influence the wildlife most crucial for ecosystem health (Cockman 2011).

Bombiculture (commercial bumblebee husbandry) is actively practiced by market growers in the Uwharries (Cockman 2011). Bombiculture can threaten native bumblebees by introducing foreign diseases (Winter, Adams et al. 2006, Mader, Shepherd et al. 2011). Despite all the challenges, implementing best management practices for pollinator conservation can improve the outlook for bumblebees and other native pollinators. “We need landscape management practices that boost native pollinator densities by increasing habitat-carrying capacity,” write Klein et al. (2007).

The type of vegetation in a landscape is an important determinant for bumblebee abundance and species richness because it affects bees’ ability to nest, reproduce, and find food. Increasing nesting sites improves pollinator habitat, but diverse forage (flowers) must also be available both locally and landscape-wide throughout active pollination seasons (Klein, Vaissière et al. 2007). In a study of pumpkin fields, those with more flowers supported more *B. impatiens* (Artz, Hsu et al. 2011). One study found that bumblebee richness, “at the 10 × 10 km square scale was positively correlated with land use heterogeneity, the proportion of grassland, and the abundance and richness of dicotyledon flowers,” (Pywell, Warman et al. 2006). Pywell, Warman et al. (2006) also found that summer bumblebee abundance increased for plantings of pollen- and nectar-rich flower margins, and to a lesser extent for planted wildflower margins, followed by mature native tussocky grass margins, then newly-planted grass margins. Traditional cereal crops supported the least abundant bumblebee populations. A study of multiple bumblebee species in Sweden found that reduced size of adult workers was significantly linked to reduced forage availability, independent of bee species identity and habitat type (Persson and Smith 2011). These researchers suggest that reduced worker size would likely have implications for overall reproduction capabilities of the colony. One way to improve forage is to incorporate bloom phases of plants in crop rotation cycles. Crop rotation has additional environmental benefits such as soil conservation and natural pest control (Klein, Vaissière et al. 2007), so managers could efficiently improve farmland’s environmental footprint by promoting pollination management alongside this practice’s other benefits.

B. impatiens have been shown to visit fewer flowers as field size increases, yet flower abundance is important (Artz, Hsu et al. 2011). Therefore, many smaller fields

could be adequate for bumblebee foraging when large contiguous tracts of land are not kept in flowers. However, connectivity of pollinator habitats may also become more important for species population dynamics as development leads to increased fragmentation (Pywell, Warman et al. 2006). Ideally, even in fragmented areas a large percentage of land tracts would provide some adequate foraging and nesting sites so that bumblebees can readily colonize across the landscape.

Conservationists recommend increasing appropriate nesting habitat for wild pollinators through management by protecting forests and other undisturbed sites for ground-nesting bees practices (Shuler, Roulston et al. 2005; Klein, Vaissière et al. 2007). The tussocks of grass and other nesting sites favored by bumblebee colonies are found in vegetated areas traditionally considered “unkempt” by yard manicurists. Bumblebees can benefit from open areas that are left untrimmed, where they can find undisturbed, abandoned rodent nests and similar ground-level cavities in clumps of vegetation. Queen bees seek exposed ground for overwintering burrows, so some less-vegetated areas of earth are important as well, particularly where they are undisturbed by farm equipment and other mechanical dangers (Osborne, Martin et al. 2008).

Competition between bumblebees and honeybees has been proposed as a factor affecting bumblebee colony success, because bees compete for limited floral resources. Goulson and Sparrow (2009) found smaller body sizes of native bumblebees when more (introduced) honeybees were present. Other research found that adding honeybee hives does not affect the number of *B. impatiens* floral visits in pumpkin fields, although another native bee, *P. pruinosa*, had reduced visits with supplemental honeybee hives (Artz, Hsu et al. 2011). Due to overlapping habitat requirements for many temperate bees, any conservation efforts to improve nesting and foraging sites or reduce pesticides are likely to benefit all of these important pollinators.

We have known about the harmful effects of pesticides on non-target wildlife species like native bees for half a century now (Kevan 1975). Rachel Carson’s arguments against pesticide misuse have resonated around the world (Carson 2002). Yet more harmful pesticides are being used each year, with repercussions throughout the biosphere. Given convincing findings on the dangers of neonicotinoid insecticides for bees globally

(Blacquière, Smagghe et al. 2012), a logical step for bee conservation is reducing the use and abuse of toxic chemicals around our farms and gardens.

Integrated pest management has become an important tool for controlling problem insects more safely. This combination of practices involves more targeted application of chemicals where deemed necessary and a host of non-chemical control measures like crop rotation and polyculture to naturally reduce pests. Integrated pest management also includes habitat improvements for natural pest predators (like predatory insects) by preserving naturally-vegetated lands in and around farms, such as forests, hedgerows, and open fields of native grasses and wildflowers. These areas benefit native pollinators in several ways: by increasing natural pest management so that pesticide use can be reduced, and by providing the critical nesting and foraging habitat for the pollinators.

Threats from Climate Change

Extinction risks from climate change are an important area of research (Thomas, Cameron et al. 2004). A review of climate change impacts on bumblebee species in Europe found that range shifts in bumblebee species have been observed, both southward and northward, as Europe warms overall (Williams and Osborne 2009). Range expansions are also noted, though it is unclear what role climate change may have played. Scientists suggest that bumblebees could be threatened directly by temperature changes or indirectly by climate change's effects on food sources or nesting sites (via small mammal populations or flooding). Cold-adapted bumblebee species may be negatively affected by extreme warm temperatures while warm-adapted bumblebees are affected by extreme cold, as climate change increases these extremes (Williams and Osborne 2009). So far evidence is inconclusive for the relationship of climate change and bumblebee declines. Studying the threat of climate change is now a priority for bumblebee conservation research (Williams and Osborne 2009).

In the concept of ecological niche, each species is understood to have optimum climate conditions and a range of tolerated climate conditions under which it can live if other ecological needs are met (Williams et al. 2007). Different species of bumblebees tolerate different air temperature ranges, and geographic distribution of species depends in part on temperature tolerance (Goulson 2003). For example, British bumblebee species

in decline have been shown to have smaller climatic ranges than their thriving counterparts, and to be most vulnerable near the edges of their climatic ranges, in part due to interactions of climate with food plant preferences and in part due to direct temperature effects (Williams et al. 2007). Williams et al. (2007) proposed a theoretical model to explain the interaction between food availability and climate change (Figure 2). The model shows how reduced abundance is expected where climate and food conditions are not adequately met for the species, particularly when poor conditions overlap (Williams et al. 2007). Given the importance of temperature for bumblebee distributions, the effect of climate change on bumblebees has been surprisingly understudied (Goulson 2003) and more research is needed to fully understand the vulnerability of bumblebee species to these shifts in temperature. Preliminary research on the effect of climate change on bumblebees has conflicting results. Colla and Packer (2008) suggest that climate is not a major factor in shaping bumblebee declines on this continent, because the species in decline are less abundant throughout their historic ranges—not just on the edges of ranges, as would be expected if climate change were the culprit.

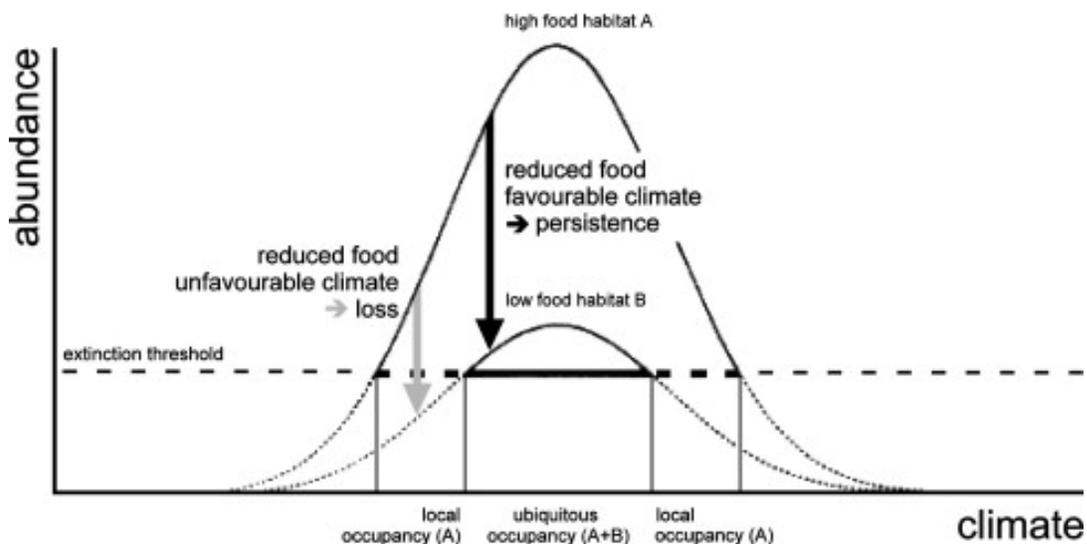


Figure 2. Abundance and Climate Under High and Low Food Conditions for an Idealized Species, (Williams et al 2007). The x-axis shows a range of some climate condition, for example temperature. The y-axis shows the species abundance, increasing above some extinction threshold. Habitat A (top line) shows abundance under high food conditions (for example flower abundance). Habitat B (bottom line) shows low food conditions. A hypothetical species would be less abundant at the edges of its climatic range and where food resources were lower. It would be least abundant in areas with the combination of low food and climatic conditions outside its optimum range.

Researchers suggest that, “Although there is good evidence to suggest that bumblebees have a minimum temperature for activity...there is no evidence that natural temperatures encountered by bumble-bees exceed the maximum with which they can cope,” (Peat et al. 2005). Bumblebees are known to thermoregulate their body temperature using internal muscles aided by other aspects of their anatomy. They are capable of warming themselves when temperatures are too cold for flight and probably of cooling their bodies, enabling activity in some temperatures that would otherwise cause overheating (Heinrich 1993). Excessive temperature remains a concern for bumblebee conservation, however. In addition to risks of individual bees overheating, workers must keep nests cool by fanning the nest with their wings, potentially reducing forage hours in excessive heat (Heinrich 1972).

Conservation Through Education

Campaigns to raise public awareness of native pollinator issues have proven highly successful (Williams and Osborne 2009). Such efforts are considered by ecologists to be a critical step toward improving bumblebee conservation. The “Education” section in this report provides information for incorporating bumblebee science into education for land managers, children, environmental activists, and the broader public.

Citizen science can be a useful tool for gathering basic ecological information about pollinating insects (Goulson, Rayner et al. 2011; Kremen, Ullmann et al. 2011). Volunteers provide valuable field hours and cover extensive habitat ranges of native pollinators, including urban, suburban, and rural areas. Some of our best bumblebee abundance studies have been made possible by the research hours of citizen scientists with just minimal training. However, insect taxa are not familiar to most people and so volunteers should be instructed in identification techniques, and such research can still be limited by inexperience (Kremen, Ullmann et al. 2011). Training volunteers in identification can open new doors for pollination education. For example, once people learn about the differences between familiar, aggressive wasps like yellow jackets and less dangerous, reluctant stingers like bumblebees they may be more excited about the diversity of native insects.

Bumblebee conservation measures are not implemented more widely due to a number of obstacles. Primarily, academic researchers have few mechanisms for influencing policy on local or national scales (Goulson, Rayner et al. 2011). Bumblebee research has been on the rise for at least the past 20 years or so, as seen in the increase of scientific publications with bumblebees listed as a key word when plotted over time, but policy change based on this information has been slow. It has traditionally been very difficult to garner public or political support for invertebrate conservation, and such work has been only sporadically taken up by nonprofit conservation groups (Black, Hodges et al. 2007; Mader 2011). When insects are linked to conservation efforts, it is usually indirectly. For example, in stream ecology researchers and citizen scientists use pollution-intolerant macroinvertebrate populations to assess stream health, but protecting particular insects is not the primary focus (USEPA 2011).

Bumblebees are relatively popular insects in north temperate areas (where they are most common), contributing significant cultural value (Williams and Osborne 2009). Relatively few bumblebee species could meet this cultural value while providing substantial pollination services to crops, so there is a danger that the vast diversity of bumblebees would be considered unimportant based on these utilitarian needs. However, the diversity of bumblebees is even more vital for pollinating the diverse wildflowers of natural systems, suggesting that a focus on bumblebee benefits for natural systems would be in line with broader conservation goals (Williams and Osborne 2009). Education is critical to help land managers of all backgrounds understand the importance of protecting diverse species of bumblebees.

Objectives

The major goal of this study was to estimate the overall health of native pollinators in a human-dominated rural/suburban environment and to increase land managers' and the broader public's awareness of native pollinators. The first specific goal was to determine the extent to which current management practices support bumblebees in the Uwharries, while tailoring recommendations for improvement to the local needs of land managers. By measuring the abundance and diversity of *Bombus* populations in fields, preserved lands, and farmlands—locations in which people are

increasingly dependent on pollination services for agriculture and for natural ecosystem health—this study provides preliminary data for a new understanding of bumblebee health in the region. The second specific goal was to develop effective education materials for improving pollination conservation in the Uwharries.

Methods

The field component of the study was headquartered in the LandTrust for Central North Carolina's Uwharries office, located in Asheboro, North Carolina. Crystal Cockman, Uwharries Coordinator for the LandTrust, assisted with site selection (including LTCNC-managed sites and other properties). She also provided background information on the management of sites surveyed. The author worked as an intern at LTCNC under Cockman's supervision during the field component of this study, June till August 2011. The field component of this study took place between June 22 and July 26, 2011.

Site Description

The Uwharries are a Piedmont area of central North Carolina that includes the Uwharrie Mountains and adjacent lands. It is centered at 35° 24' 6.51" N, 80° 3' 32.19" W and extends across several counties of North Carolina. The Uwharries are within the "southeastern mixed forests" ecoregion (Olson, Dinerstein et al. 2001). The area includes Uwharrie National Forest (federally designated in the 1960's), a state park, lands protected and monitored by The LandTrust for Central North Carolina, and other public and private lands, all within close proximity of heavily developed lands.

Three study sites were selected along the Uwharrie River on the McPherson Uwharries Farm, the Capel Property, and the Grissom Property, and designated the Garden, Burned Field, and Restored Prairie sites respectively (see Figure 3). Each of the study sites was chosen due to the presence of open fields of approximately the same acreage with mixed grasses, forbs, and shrubs. The sites were bordered by mixed hardwood forest, a paved or dirt road with fewer than one car per minute, and nearby water access. Within the sites two transects were designated for repeated bee observations throughout the study. Each transect was selected near the edge of a field in

an area with relatively high diversity of flowering plants for that field as a whole, as assessed by prior property visits (including walking the entire property) by the author or by Crystal Cockman. That is, the transects were selected for optimal forage properties based on informal vegetative analysis. Each transect was a rectangle measuring 100m by 3m (300m² or .03 hectares), set lengthwise along a wide packed dirt path. Each transect spanned a variety of slopes and aspects. One transect at each site was bordered by woods. A second transect (also 100m by 3m) at each site was about 300m from the end of the first transect, running along a different packed dirt road or mowed path.

The three main sites included: recently burned fields which were also mowed historically for the past 40 years or so (left to natural regeneration, chemical free), fields burned several years ago and replanted with native grasses and wildflowers (shrubs here were spot-treated with herbicide), and chemical-free garden sites that have been mowed frequently and partially cultivated but not burned. Management histories for all the sites are summarized in Table 1, and more detailed descriptions are included in Appendix A. At one site (Restored Prairie), an extra transect was briefly constructed and observed only from July 21-24 due to the high quality forage that came into bloom during the end of the study in one section of this site. This section had been burned and replanted with native wildflowers in 2011. A vegetation survey on July 24 indicated the extra transect had approximately 100 blossoms per meter at this time. See Appendix B for a map of the entire Restored Prairie site.

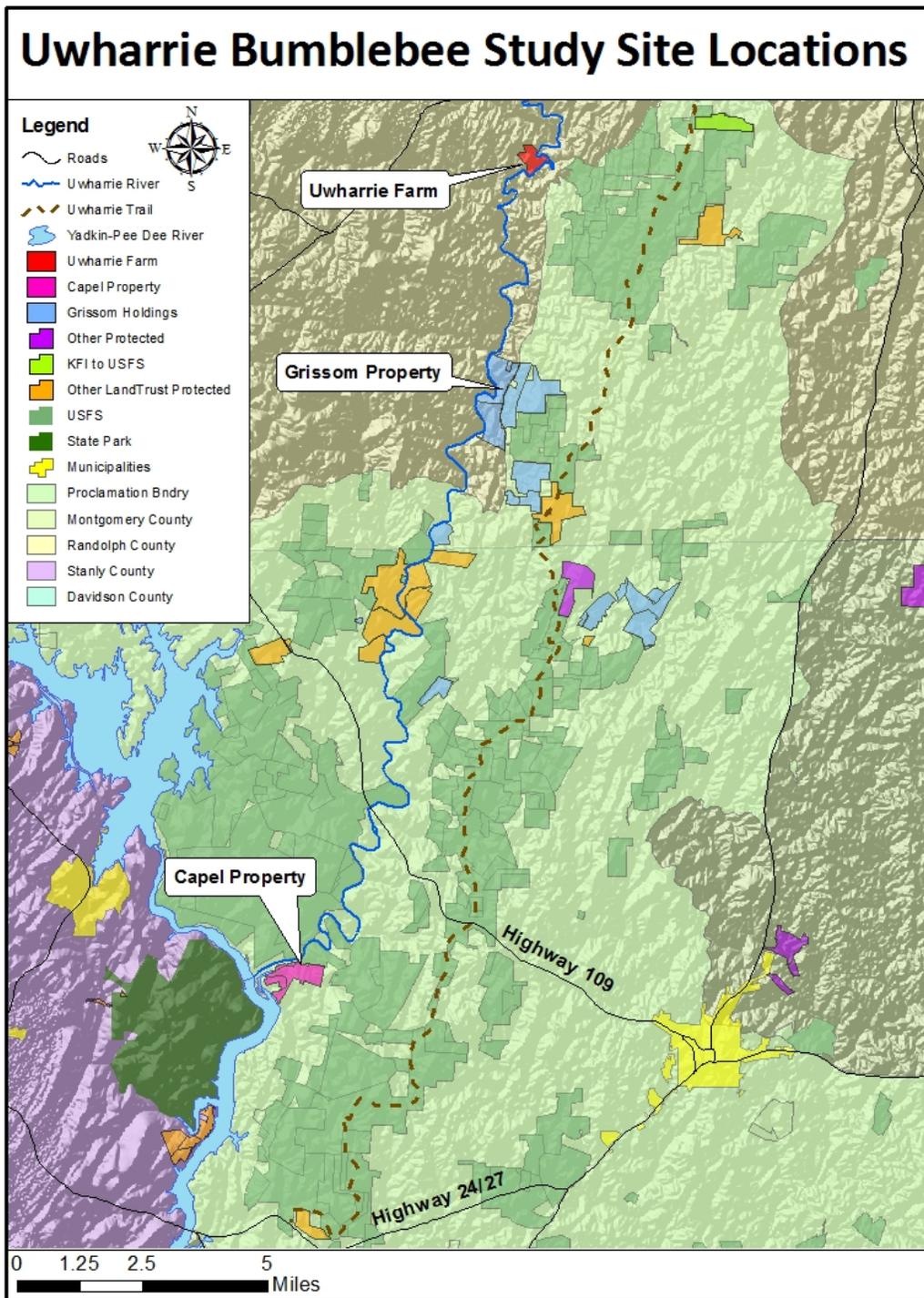


Figure 3. Study site locations. Topographic map showing the locations of three survey sites along the Uwharrie River in central North Carolina: the Capel Property (Burned Field Site), Uwharrie Farm (Garden Site), and Grissom Property (Restored Prairie Site). Map by Crystal Cockman (2011).

Table 1. Description of past history for sites used in the pollinator population survey. The three main site locations represent different management regimes. In one location, two different sites were used. The Restored Prairie extra transect (*) was surveyed only July 21-24, 2011.

Study Site	Burned Field 	Garden 	Restored Prairie 	
Detailed Site Transect Name	Burned Field	Garden	Restored Prairie primary transects	Restored Prairie extra transect*
Land Trust Site ID	Capel Preserve	McPherson Farmland Conservation Easement	Grissom Private (NWSG-1)	Grissom Private (NWSG-5B)
Long-term Mgmt. (~5-40yr)	Mowed annually	Pasture, lawn, and garden	Pasture or fallow, possible row crops	Pasture or fallow, possible row crops
Short-term Mgmt. (~1-5yr)	Burned 2010, unmowed	Mowed weekly to monthly	2006 herbicide treated, burned annually	2006 herbicide treated, burned annually
2011 Mgmt. (Jan-Jun)	None	Mowed weekly to monthly	Shrubs spot-treated with herbicide	Shrubs spot-treated with herbicide
Natural Vegetation	Native and non-native grasses, forbs, shrubs			
Planted Vegetation	none	Cultivated with mixed crops	Seeded in native prairie grasses and wildflowers 2006 (none in 2011)	Seeded in native prairie grasses and wildflowers 2006 and 2011

Experimental Design

Experimental design was broadly based on a study that surveyed bumblebees from several locations in eastern North America (Colla and Packer 2008). Additionally, this study examined which non-native, common, and rare bumblebees are present in Piedmont North Carolina to provide preliminary data on the species composition of Uwharries bumblebee populations.

The expected results of the study were to reject the null hypotheses that management regime is not linked to bumblebee abundance or diversity, therefore supporting the alternative that bumblebee pollination depends on the management regime of the habitat.

This ten-week study specifically looked at how species diversity and abundance metrics for bumblebee species differ between fields at sites in near proximity to each other but far enough to avoid crossover between colonies (Goulson 2010). The study relies on counts of pollination visits (bees observed visiting flowers) at the sites to provide an over-all picture of relative pollination health at the site.

As in the methods of the Dukas (2005) bee predation study, I observed each site on successive days, counting all individual bumblebee sightings within a set time frame (20 minutes), with repetitions. The individual counts were recorded as bumblebee density data. Each of the six original transects were observed between 3 and 7 times in the morning and between 3 and 7 times in the afternoon throughout the study. (Morning observations were started between 7 and 10:30am, while afternoon observations were started between 3 and 8pm.) In order to ensure the surveys captured optimal daytime temperatures for the bees, start times were adjusted earlier and later to capture the coolest temperatures. When the start time began to overlap with dew times (wet vegetation) around sunrise, bumblebees were not yet actively flying and were seen sitting on vegetation warming the thorax before flight. Start times could not be adjusted beyond this point. Temperature, weather conditions, cloud cover, and any additional notes (such as thunder) were recorded for each observation. Additionally, the average percent shade covering each transect was estimated during each observation period. The shade could be from cloud cover, shadows from trees, or other shade blocking the direct insolation of the vegetation in the transect. The percent shade was estimated by the surveyor before and

after each observation period and these numbers were averaged for an estimate of transect area shaded.

One observation period was 20 minutes. During this time I walked the transect (along the dirt path) approximately twice up and back ($100 \times 3 \times 4 = 1200$ square meters total for a rate of approximately 60 square meters per minute observed). Using visual and auditory cues I searched the vegetation for bumblebees. These large bees are identifiable from a distance of up to about 20 feet, and I learned to distinguish their distinctive buzz from wasps, other bees, flies, and other common insects. Each bumblebee that landed on vegetation in the transect was recorded, and its species was determined in the field if possible. The flower(s) the bee visited in the transect were recorded (Justice, Bell et al. 2005). Unusual behavior was noted, including inactive (non-foraging) bumblebees. The first bumblebee observed in each transect was captured if possible in a jar containing ethyl acetate, which quickly anesthetizes and eventually kills the insect. Success rate for attempted versus actual captures by holding the glass pint jar beneath the bee while it visits a flower and capturing it with the lid was about 50 percent. (Bumblebees are very approachable while they forage; they don't often respond to the researcher or the kill jar before they are inside it.) There is some possibility that bees could be recounted if they were not captured, particularly as I passed the same area of the transect more than once. However, I visually followed bees when they left the transect to be conscious of not recounting bees that were not captured.

During the first transect observations additional data was collected to estimate the amount of blooms available for forage. Each flowering plant in the transects with open blooms or buds and the number and size of the flowers was recorded. This allows for an approximate comparison of bee visits per flower for each transect. Differences in bee populations after normalizing for available forage could indicate other aspects of the habitat are influencing populations. For example, a site may have better nesting habitat or fewer pesticides in the vicinity.

Vegetation Survey

A vegetation survey at the Restored Prairie, Burned Field, and Garden sites was conducted on June 22 and 23, 2011 at the beginning of the bumblebee observations. At

the Restored Prairie and Burned Field sites, this survey was conducted on the same transects as the bee study. For the vegetation survey at the Garden site, Transect 1 from the bee study was used for the vegetation survey, but not Transect 2 from the bee study. Instead, a vegetation survey on a transect of the same area was conducted at a different location on the same field about 100 meters from the Transect 2 bee transect, where the dominant species were the same species of grass, and the wildflowers were considered similar in both diversity and abundance. (This vegetation transect was originally planned as Transect 2 for the bee study but had to be relocated due to the landowner's cattle moving into this area of the field).

A second vegetation survey took place at the Restored Prairie and Burned Field sites on August 4, 2011. An August survey of the Garden site could not be completed, although field notes about the vegetation from the bee surveys at the Garden site in early August provide some estimates of forage availability.

The vegetation survey for each transect was conducted by walking along the transect and counting each plant that was in bloom. All flowering plants in bloom were counted regardless of any bumblebee preference for flowers of particular species. The flowering plants were identified to species where possible but were described carefully in field notes and assigned an identification number if species was unknown by the researcher. In this way a total count of unique species for each site could be obtained. For each blooming plant, the number of blossoms was also counted and assigned to a category of 1-5 blossoms, 6-10 blossoms, etc.

I assessed relative bumblebee abundance and diversity from the field observations. Relative abundance by treatment site was assessed in terms of overall abundance, bees per observation period [presence/absence], and bees per unit of forage (flower blooms per area). Species diversity was also calculated for all sites. I noted any study-wide correlations of abundance or diversity with forage availability, approximate light level, temperature, weather conditions, date, time of day, proximity to a road, proximity to a forested area, elevation, aspect, slope, and flower type visited. Additionally, I determined the presence/absence of uncommon species study-wide.

Collected bee specimens were frozen between layers of paper in a plastic container until January 2012. I then used calipers to measure each bee's head size as a

proxy for overall body length (Nijhout 2012). I examined each bee under a microscope, successfully sexing them and identifying them to the species level. The bees were dried in a supervac for 3 days, then reexamined in glass tubes. The bees were then rehydrated (Nijhout 2012) in order to remove them from the tubes, then they were dehydrated again to determine drymass. The head diameter and drymass were compared across sites, accounting for date of collection, to determine the health of the colonies that produced the specimens at each site.

Results

Environmental Conditions

Shade: The burned field on average was the most shaded during transect observations with 69% shade estimated, as seen in Figure 4 below. The restored prairie (49% shade) and garden (50% shade) sites had approximately equal shading to each other.

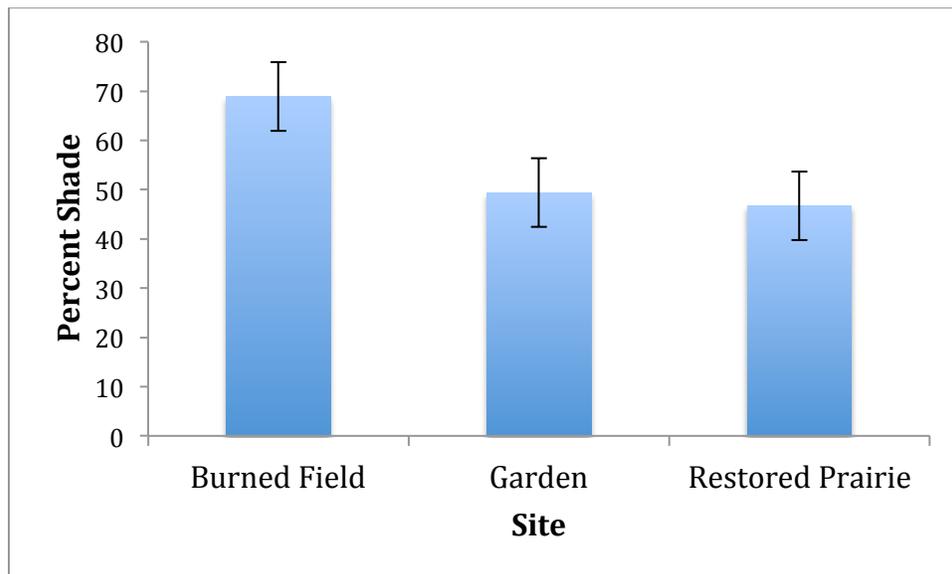


Figure 4. Light availability by site. The percent shade was estimated at each transect during bee surveys for three sites in central North Carolina (average \pm standard error).

Temperature: The temperature recorded at each transect during the observation periods are seen in Figure 5 below, with the active flight temperature range of bumblebees marked for comparison. All surveying occurred in temperatures warmer than the middle of the bees' preferred range, and approximately half of the surveys occurred in

temperature warmer than the range's extent. The average maximum daytime temperature was warmer than the preferred bumblebee range during most days of June, July, and August 2011 in the Uwharries.

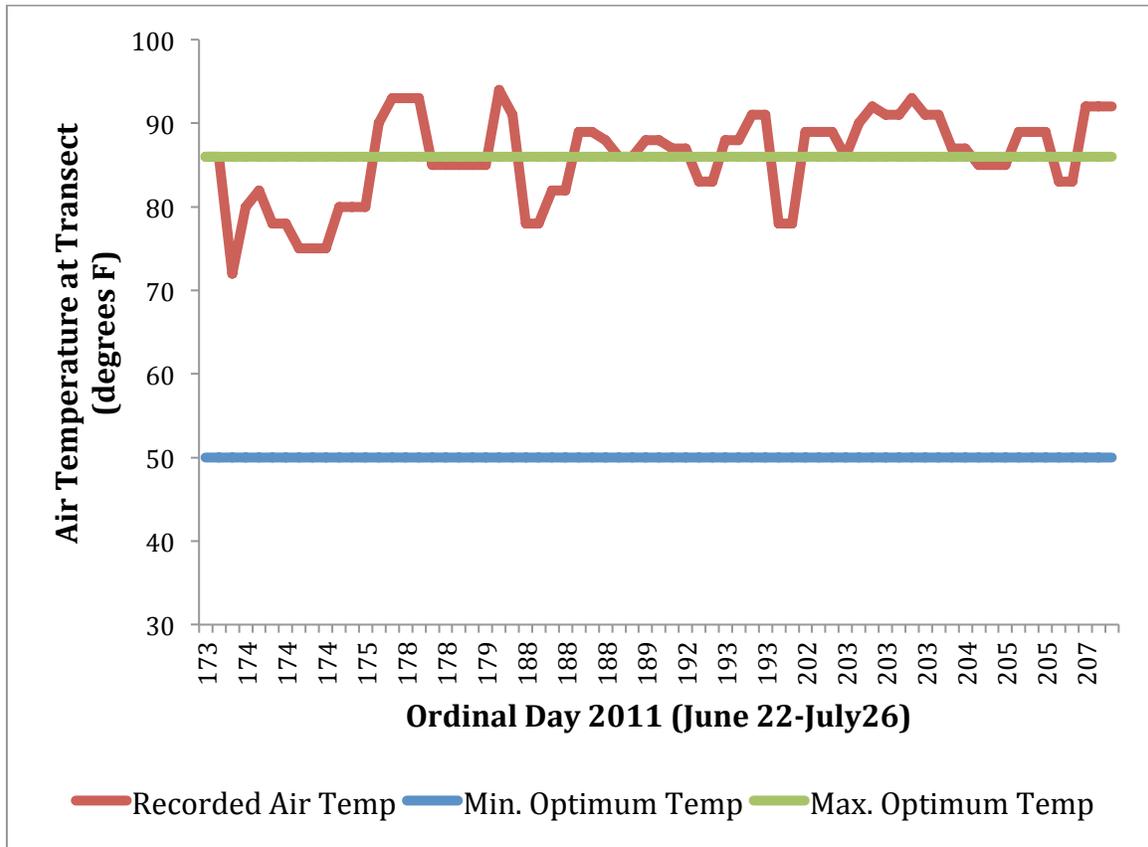


Figure 5. Air temperature and bumblebee flight temperature. Air temperature in degrees Fahrenheit of shaded thermometer (x axis, red line) during each observation period, listed by ordinal day (1=January 1, 2011), including all sites. Average air temperature was 86° F. Blue and green lines represent the optimum temperature range for active flight in bumblebees (Winter, Adams et al. 2006).

Average air temperature from the shaded thermometer readings are compared for each site in Figure 6 below. The averages were all within two degrees Fahrenheit of each other, although the average temperature at the Burned Field site was slightly warmer (87° F), followed by the Garden site (86° F), and the Restored Prairie site (85° F).

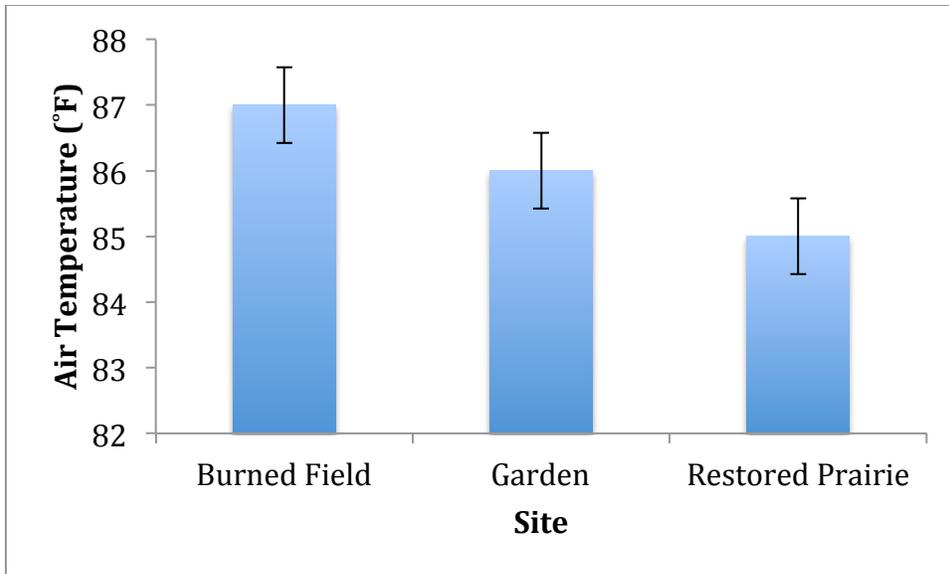


Figure 6. Average air temperature by site. Air temperature in degrees Fahrenheit of shaded thermometer averaged from all observation periods for the Burned Field (87° F), Garden (86° F), and Restored Prairie (85° F) sites in central North Carolina (average \pm standard error).

Vegetation: The plant species observed in the vegetation surveys included the families below (Table 2). Table 2 excludes four unknown families for plant species that could not be identified. Also in Table 2 are the number of total plant species and the number of total blossoms counted from each site for the June vegetation survey and from the Burned Field and Restored Prairie sites for the August vegetation survey.

The June vegetation survey results by site are seen in Figure 7A. The garden site had the greatest species richness with 22 species. The restored prairie (14 species) and burned field (13 species) sites had about the same species richness, although the restored prairie had slightly greater species richness.

Field notes from the garden site in August indicate there were fewer blossoms, fewer blooming plants, and probably fewer blooming plant species at this site compared to in June. In particular, hundreds of clover and plantain blossoms that covered the lawn in June were no longer in bloom by August. This suggests that it would be inaccurate to extrapolate from the increase in blooms and blooming species from the other two sites that there was a comparable increase in flowers at the garden site.

Table 2. Vegetative Survey Plant Data. Plant list of plant families with representatives blossoming in transects, listed by site, as identified in June and August surveys, and number of species observed at three sites in central North Carolina (600m² each) and during August vegetation survey at two sites.. Number of blossoms (or inflorescences functioning as single landing location for bumblebees) for each flowering individual were counted in the field. No data was obtained from the Garden site in August. Photo shows a bumblebee forage species found in the Restored Prairie transect, *Passiflora incarnata*.

Passionflower <i>(Passiflora incarnata)</i> A local favorite for bumblebees! (Photo by Mike_tn)	Partial List of Plant Families By Site (June and August)		
	Burned Field	Garden	Restored Prairie
	<i>Apiaceae</i>	<i>Asteraceae</i>	<i>Apiaceae</i>
	<i>Asteraceae</i>	<i>Cucurbitaceae</i>	<i>Asteraceae</i>
	<i>Fabaceae</i>	<i>Fabaceae</i>	<i>Fabaceae</i>
	<i>Lamiaceae</i>	<i>Lamiaceae</i>	<i>Lamiaceae</i>
	<i>Melastomataceae</i>	<i>Malvaceae</i>	<i>Passifloraceae</i>
	<i>Phytolaccaceae</i>	<i>Oxalidaceae</i>	<i>Phytolaccaceae</i>
	<i>Plantaginaceae</i>	<i>Plantaginaceae</i>	<i>Plantaginaceae</i>
	<i>Poaceae</i>	<i>Rosaceae</i>	<i>Rosaceae</i>
	<i>Scrophulariaceae</i>	<i>Solinaceae</i>	
		<i>Vitaceae</i>	
Total Species (June Survey)	13	22	14
Total Species (August Survey)	19	no data	17
Total Blossoms (June Survey)	640	1840	1550
Total Species (August Survey)	4340	no data	2250

The August vegetation survey results are seen in Figure 7B. The restored prairie (17 species) and burned field (19 species) sites had about the same species richness, although the burned field had slightly higher species richness.

The results of the blossom counts by site are summarized in Table. The burned field site had the greatest increase in blossoms between June and August, primarily due to small (about 10cm height) ground cover flowers carpeting the site in August but not in June. The restored prairie site had an increase in the number of blossoms as well. The garden site had the most blossoms of the three sites in June, closely followed by the restored prairie with many fewer blossoms at the burned field. In August the burned field had many more blossoms than the restored prairie.

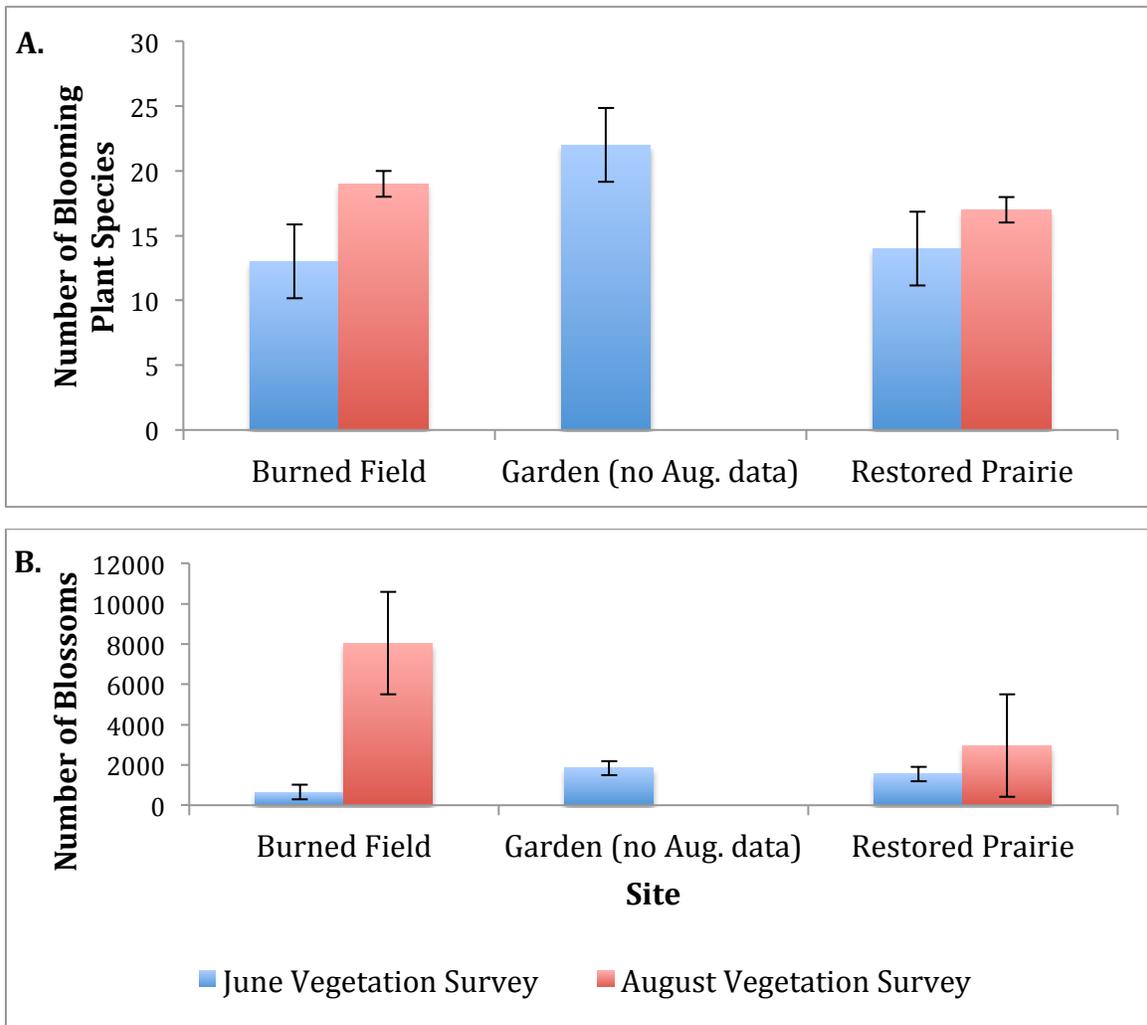


Figure 7 A and B. Vegetation Survey by Site. Results of the June vegetation survey from three sites in central North Carolina, comparing the number of blooming plant species identified in two transects (A), and the number of blossoms (B) (average \pm standard error), (600m² total area per site).

Diversity

The field survey observations included 61 observation periods of 20 minutes each at the three sites, with additional observation periods at the field planted in 2011 with wildflowers, at the extra Restored Prairie transect. Overall, low numbers of bumblebees were observed (n=41 for three main sites, n=102 total with the difference from the extra Restored Prairie transects).

Over all the sites two common species of bumblebee were found: *Bombus impatiens* (common eastern bumblebee) and *Bombus bimaculatus* (two-spotted

bumblebee). Figure 8 below shows the species with the markings used to distinguish them. Both species was found at all three sites. Neither of the two species is listed on the Xerces Society for Invertebrate Conservation’s Red List of threatened insects, the primary list for pollinator status in the United States (The Xerces Society for Invertebrate Conservation 2011). No rare bumblebees were found in the study, and of more than 40 species of bumblebee in the United States fewer than five percent were observed at all of the Uwharries sites combined during summer forage.

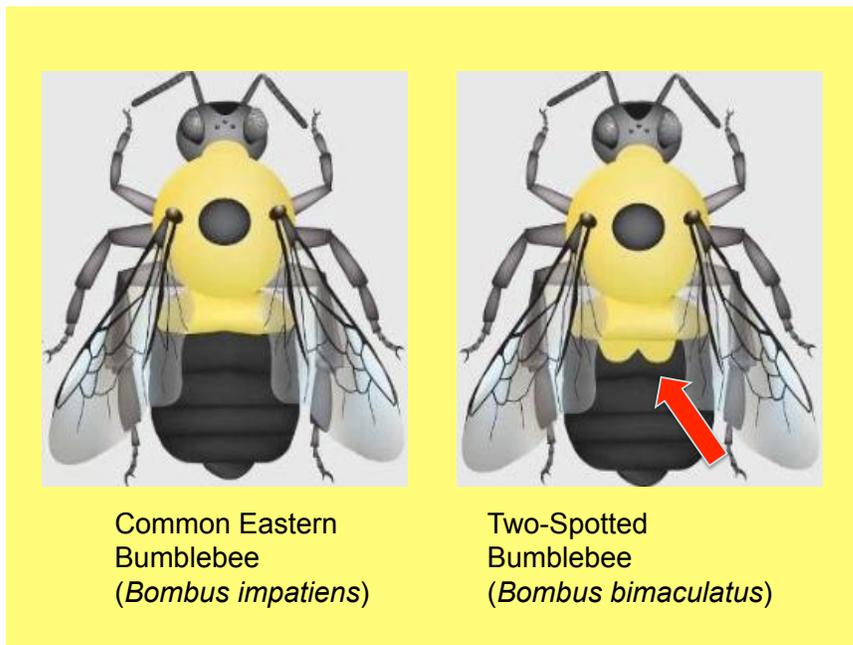


Figure 8. Bumblebee species found in the Uwharries, summer 2011. The 20 collected bumblebee specimens included 15 individuals of *B. impatiens* and 5 individuals of *B. bimaculatus*, identified by anatomy in the lab. The primary distinguishing feature between these two species is the presence of two yellow spots in the center of the second abdominal segment of *B. bimaculatus* (red arrow). Additional markings used for identifying these species from other bumblebees are: the first abdominal segment is yellow, rear abdominal segments are black. Thorax is mostly yellow with black spot between wing bases. Patch of hair at “scruff of neck” is yellow (Modified from Xerces 2012).

Floral Visits

The field surveys showed that the bees observed in the transects differed in abundance between the three sites. The most bees per 20 minute observation period were seen at the Burned Field site, followed by the Garden site and finally the Restored Prairie site. These results are shown in Figure 9 below.

The most bumblebees per forage unit were also observed at the Burned Field site compared to the other two sites, as seen in Figure 10 below.

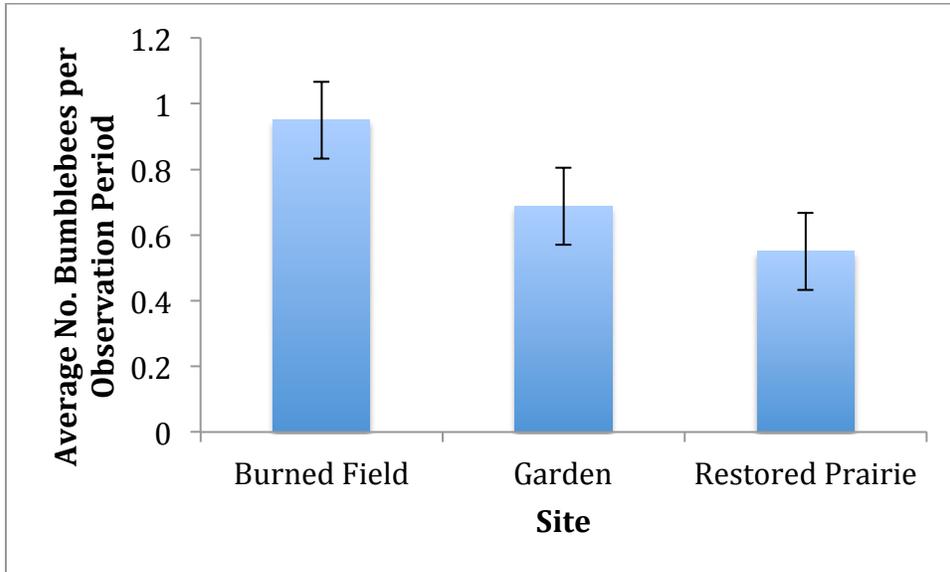


Figure 9. Bumblebee abundance by site. Number of bees observed in Burned Field, Garden, and Restored Prairie sites in central North Carolina per 20 minute observation period (average \pm standard error).

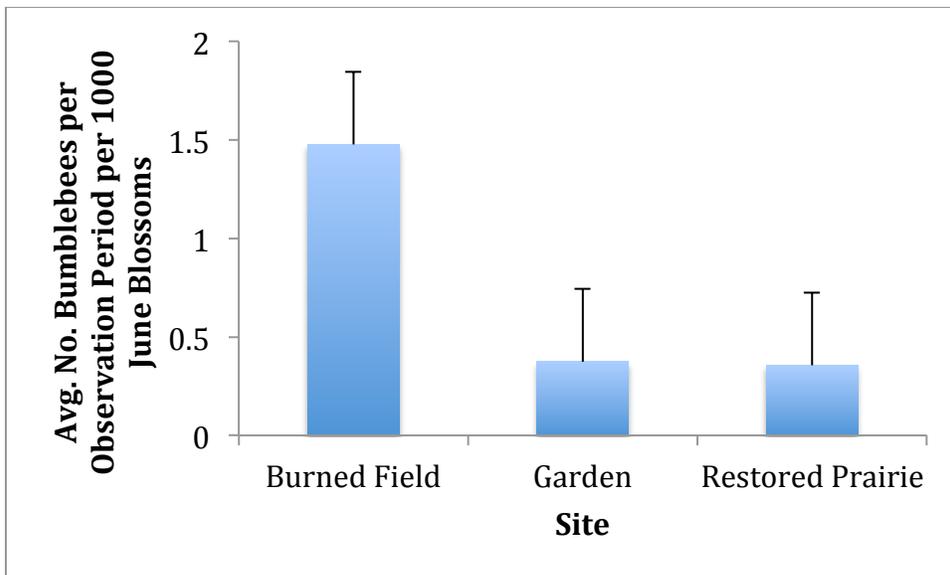


Figure 10. Bumblebee abundance per forage unit by site. Number of bees observed in Burned Field, Garden, and Restored Prairie sites per 1000 blossoms per 20 minute observation period are compared. Number of blossoms is based on June vegetation survey at each site in central North Carolina (average \pm standard error).

Bumblebee Size

Results of head diameter and bee dry mass indicate that there is a strong correlation between the two, as seen in Figure 11 below. Overall average biomass and head size did not increase with time during the weeks of the study.

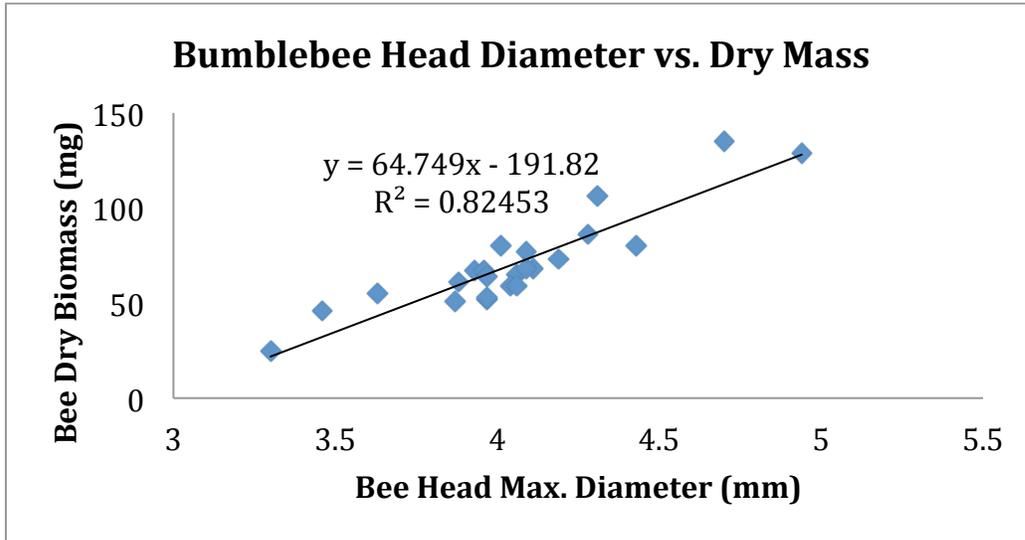


Figure 11. Average dry mass (g) of bees compared to average head diameter (mm) collected from Garden, Burned Field, and Restored Prairie sites in central North Carolina.

There was no significant difference in the biomass of bees from the three sites, as seen in Figure 12 below.

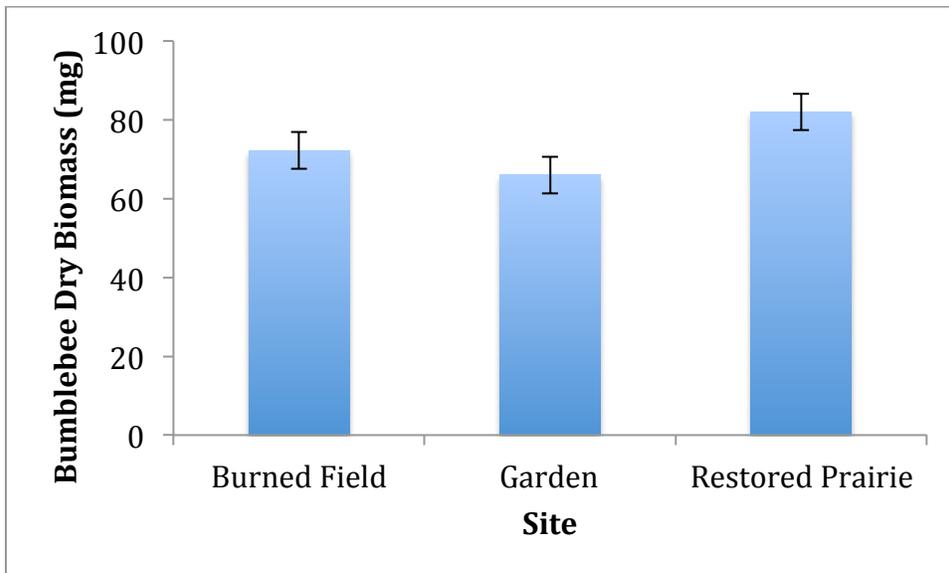


Figure 12. Average dry mass (mg) of bees collected from Garden, Burned Field, and Restored Prairie sites in central North Carolina (average \pm standard error).

Discussion

The fact that no rare bumblebees were found in the study, including species whose ranges have recently included North Carolina, is of primary concern. For example, *Bombus affinis* (Rusty-patched Bumblebee), once common in North Carolina but in decline throughout its range, was not seen in the state in surveys conducted in 2008 (Colla and Packer 2008). In addition, it is discouraging for bee conservation that a low overall diversity was observed, with even common species “missing”. This study supports the growing body of data worldwide showing Bumblebee species declines. The single year time period of summer forage limits the strength of the study to witness this decline in the Uwharries, but any future studies in the region should be compared to these results to determine whether the species observed remain with present population numbers, and whether other species are truly present.

The absence of all but two bumblebee species in the Uwharries sites may be due to a true lack of other species in the Uwharries overall, a lack of other species during summer forage (June-July), or to limitations of the study. Other species may be present in different habitats than those surveyed, such as in the shade of woods. Alternatively some species may have different temporal patterns, foraging with more enthusiasm earlier or later in the summer when temperatures are more conducive to ectotherm metabolic needs. The land management practices of all of the sites may have been inadequate for some species nesting or foraging needs, with too few nesting sites or flowers. There could be a high level of pesticides at the sites from neighboring farms. Even if the sites offered perfect habitat, landscape-level land uses detrimental to the overall viability of some species could have affected the ability of bees to colonize in these habitat patches. Many more bumblebee individuals were observed in the extra transect from the Restored Prairie site. The extra transect had many more blooms, while nesting locations and landscape effects were identical to their nearby Restored Prairie primary transects. Even though diversity was not observed to be greater at the extra transect, additional observation periods could have shown that rarer species were present at these choice foraging locations.

Due to limitations of the study sites there was no way to conduct a controlled study with repetitions of any single best management practice. Therefore the results are

most important as a comparison between management regimes. The field survey's showing that the bees observed in the transects differed in abundance between the three sites is of interest because it suggests that the sites offered differing conditions for bumblebees. The most bees per 20-minute observation period were seen at the Burned Field site, followed by the Garden site and finally the Restored Prairie site. It could be that the habitat best suited to Uwharries bumblebees is an open field that has been maintained by burning. The Burned Field site has only been burned once, however, so the bees may be present due to previous management practices at the site (annual mowing). Both mowing and burning has been relatively infrequent at the Burned Field site, while the Garden site is more frequently mowed and the Restored Prairie site has been burned more than once. Mowing and burning has been shown to at least temporarily reduce bee populations (Claire 2002), although it is important for maintaining open habitat and diverse forage vegetation (Cockman 2011; Mader, Shepherd et al. 2011). It could be that the bees at the Burned Field site were able to escape damage from the burning and mowing because of the timing of these events (before the bees were actively foraging) or their spatial extent (i.e. more skips were included and other havens during the burn could have been more easily accessed). The areas of the Garden site that are mowed at least once a week are much less likely to leave any bumblebee nests in that area undisturbed than if mowing was less frequent.

Transects at the Burned Field had the greatest amount of estimated shade during the study. Bumblebees may have been more abundant in these shadier locations during the warm daytime temperatures of June and July because they sought to avoid direct insolation to prevent overheating while foraging. Shade could also have affected the vegetation, preventing flowers from wilting as quickly during the day as in sunnier locations.

Future Directions

This study only assessed the relative abundance of actively-pollinating bumblebees without attempting to calculate nest density. Ideally, a citizen science study can eventually be organized for North Carolina that uses hundreds of trained volunteers to survey an area for bumblebee nest densities, which would provide more information on

whether managed lands provide habitat needs (Osborne, Martin et al. 2008).

Additionally, captured bees can be used to estimate nest density through genetic kinship techniques, as in Knight et al. (Knight, Martin et al. 2005).

Increased monitoring through future surveys should also include more sites with very attractive, abundance floral resources (as with the Restored Prairie extra transects). This would hopefully enable a larger sample size and more powerful statistical analyses.

The results of this study, including all specimens, were contributed to The LandTrust's project on inventorying species of the Uwharries. Additional research could further aid the conservation organization in prioritizing land parcels for targeted conservation of ecosystem services and in deciding which best management practices to implement on their properties.

Recommendations for Uwharries Land Managers

For planning conservation practices for bumblebees and other native pollinators, I recommend that land managers consider these primary factors to focus their efforts: nesting sites, forage availability, and protection from pesticides and mechanical dangers (like frequent mowing). Additionally, climate change is a concern for bumblebee conservation more broadly. Specific recommendations are included here with background information for land managers in the Uwharries, tailored to management practices common in the region. The recommendations are based on the field study of bumblebees in the Uwharries at the Burned Field, Garden, and Restored Prairie sites, as well as on extensive literature review.

Plantings to Attract Pollinators

Planting diverse forage that blooms year-round is the best way to support bumblebees and other native pollinators. Plant species selection should ensure compatibility with land manager's needs and with ecosystem functions. Ideally plants should be local to central North Carolina because those flowers will be easier to acquire, more effective for attracting and supporting local bee populations, and will not risk introducing nonnative plants to the fragile Uwharries ecosystems. Use caution that other species are not disturbed. See Appendix E for a "List of recommended plants for

pollinator conservation in central North Carolina” (Roos 2012). Habitat restoration projects can be considered where existing vegetation fails to support diversity and ecosystem functions. For example, land owners with fallow fescue grass fields (common in the Uwharries) can alter this land without risking disturbance for many native species.

Appendix E includes links to more specific resources for implementing land management practices. For example, the “Farmland conservation for pollinators guides” for organic and conventional farms allows agricultural land managers to assess the areas of their farms where pollination conservation practices can be improved (Xerces 2012).

In addition to forage species, plantings can include native clumping grasses (bunchgrasses) that provide complexity in the ground-level environment. This may entice bumblebees to construct their nests on the site (Mader, Shepherd et al. 2011). Once established, native grasses also require less intensive management than fescue, so mowing can be reduced or eliminated, for example (see “Mowing” section below). North Carolina Piedmont bunchgrass prairie species include little bluestem, also called beardgrass (*Schizachyrium scoparium*) and Indiangrass (*Sorghastrum nutans*), both of which are already being planted in the Uwharries to restore habitat for native wildlife (Cockman 2011).

Prescribed Burns

The LandTrust and other conservation groups in the Uwharries are increasing their use of fire as a management tool (Cockman 2011). Regionally prescribed burns are becoming more common, with diverse land protection groups embracing the ecological benefits to pine forests, meadows, and other native ecosystems.

There are many known ecological benefits to burning, especially for previously marginalized land like fescue fields (Black, Hodges et al. 2007).

Burning can create open space native prairie habitat, a historical ecosystem for the Uwharries than conservation specialists aim to encourage by preventing sweetgum (*Liquidambar styraciflua*) and other fast-growing trees from regenerating on fallow fields (Cockman 2011). However, there is little known about the effects of burning on pollinators and pollination services (Black, Hodges et al. 2007). Recent research in the Blue Ridge Mountain Province of North Carolina examined the effects of prescribed

burns, mechanical shrub control, and a combination of the two techniques on insect pollination in forests (Campbell, Hanula et al. 2007). This extensive study found that floral visits increased the most with the burn/shrub cutting combination, which correlated with smaller tree diameter and cover and with increased herbaceous plant growth.

The results of this bumblebee study suggest that the burned sites in the Uwharries may enhance pollination in a similar way. However, burning should be practiced carefully to protect nesting and foraging bees. Pollination conservation practices for prescribed burns include burning no more than 30 percent of a site each year, leaving skips (small vegetation patches) unburned in the burned area as “potential micro-refuges,” burning infrequently (3 to 10 years between burns are recommended for full pollinator recovery), and avoiding hot, intense fires whenever possible. Additionally, conservationists suggest that, “Low-intensity prescribed burns conducted early or late in the day, or from late fall to early spring, are not only preferable for pollinators but also reduce impacts on other wildlife species such as reptiles and ground nesting birds,” (Black, Hodges et al. 2007).

The LandTrust and the Greater Uwharrie Conservation Partnership have largely prescribed burns for the purpose of improving natural habitat for wildlife (Cockman 2011). (For example, Uwharries conservations are concerned about the grasshopper sparrow (*Ammodramus savannarum*) which relies on the rare prairie habitat maintained by burns.) However, the Partnership’s interest in managing fire to support wildlife has not specifically taken into account the needs of pollinators. Some management recommendations for pollinators would be impractical in the Uwharries. In particular, many areas must be burned annually to remain open at all due to the rapid regeneration of sweetgum, unless another control method (herbicide) is used as well (Cockman 2011). Burning should be practiced in conjunction with additional restoration methods, such as planting native grasses and wildflowers.

Mowing

Managed open space in the Uwharries is most often maintained by mowing. Roadsides, fallow fields, suburban yards, golf courses, and utility right-of-ways are all mowed (Cockman 2011). The frequency of mowing ranges from several times a week to

once or twice annually, with different weights of equipment used accordingly. The effects of different mowing regimes on pollinators largely depends on the balance of threats to pollinators, forage, and nesting sites from the mowing with benefits of maintaining the favored habitats. The *Pollinators in Natural Habitats* management primer states, “The differences between an ultimately beneficial mowing regime and a detrimental one are technique, timing, and scale,” (Black, Hodges et al. 2007). As with burning, it is recommended that no more than one third of the area be mowed at one time, that mowing frequency be decreased overall, and that some areas (edges for example) be left undisturbed for the entire season.

Agriculture

Farms that use little or no chemical pesticides, herbicides, or fertilizers can benefit pollinators on local and landscape scales (Holzschuh, Steffan-Dewenter et al. 2008). Farms with reduced machine use also help protect pollinators. Additionally, farm size is important, with larger farms eliminating important edge habitat and reducing the diversity of land use types (Tschardt, Klein et al. 2005). The small, pesticide-free farm that provided the Garden Site for this study is exactly the type of landscape that can be easily improved for bumblebee habitat. This farm already has undisturbed areas on edges and protected woodlands into perpetuity thanks to the owner’s initiative to create a Farmland Conservation Easement on the property adjacent to the Uwharrie River. Wild flowering species should be encouraged in these areas and throughout the property. Mowing disturbance could be reduced by practicing the recommendations in the “Mowing” section. The Garden Site also offered numerous cultivated plants for horticultural and agricultural purposes, which improved the diversity of forage for bumblebees over many suburban lawns.

Most farms are larger than the Garden Site farm, and would have a larger impact on bumblebee habitat, for better or worse. Research shows that bumblebees observed in fallow strips near farmland increased in diversity by 150% when the farmland was converted from 5% organic to 20% organic crops (versus conventionally managed agricultural crops), and increased overall bee species richness and species richness of solitary bees as well (Holzschuh, Steffan-Dewenter et al. 2008). The researchers suggest

that bees nesting in these fallow strips are better able to meet floral forage needs among broadleaf weeds in the organic fields. Farmers may be able to tolerate some weeds, but alternatively the bees should also be able to thrive on mixed crops or cover crops allowed to flower (Holzschuh, Steffan-Dewenter et al. 2008).

A concern with cultivated vegetation is pollinators' diets. Monoculture crops, particularly those with little or no attraction for bees (like corn), can limit bees' access to nutritional diversity important for metabolism and feeding young (Mader, Shepherd et al. 2011). Some monoculture plantings are better than others; for example, bumblebees seem to benefit from cranberries and blueberries, which they also pollinate impressively. On a smaller scale, diverse crops planted in gardens and on mixed produce farms can be favorites for bumblebees. Melons, tomatoes, peppers, squash, beans, potatoes, and many kinds of decorative flowers are some of the plants recommended for attracting native pollinators. An important consideration is whether vegetation provides extended, overlapping bloom times for forage through the bees' active seasons (in the Uwharries, early spring through late fall) (Vaughan and Black 2008).

In both agricultural and conservation landscapes managers often use herbicides to control weeds and invasive plants, but pollination conservation can be addressed even when chemicals are used (Vaughan and Black 2008). First, it is critical to ensure that forage (diverse, blooming flowers) are abundant from early spring through late fall, when bumblebees are active in this region, so any tolerable flowering plants should be shielded from chemicals. The application of herbicides should be directed carefully, with swipes for example, rather than with broad sprays or pellets. Pellets are particularly dangerous for bees, whose dense pile and foraging activities collect the chemical crumbs and transfer them to vulnerable young in the nest (Mader, Shepherd et al. 2011).

Grazing intensity is an important consideration for pollinator conservation, because large livestock has the ability to damage bees and nests and to alter vegetation to make it less suitable for forage and nesting (Mader, Shepherd et al. 2011). However, limited grazing with smaller herds rotated slowly through the landscape can be suitable for pollinator habitats. According to some researchers (Smallidge and Leopold 1997), when managed correctly livestock can help maintain "an open, herbaceous-dominated plant community that is capable of supporting a wide variety of butterflies and other

pollinators,” (Black, Hodges et al. 2007). The Garden Site farm has some grazing use, but very few animals are kept (two steers). However, selective feeding could still disrupt some native plant populations important for pollinator habitat. If the animals can be rotated from pasture to pasture (leaving areas to recover intermittently), this pressure would be reduced.

Introductions of foreign bees to the local environment may threaten local bumblebee populations and behavior (Goulson 2010). There are risks from both foreign-bred strains of native species shipped in and non-native species of bees. Colony collapse disorder and other challenges with commercial honeybees (vanEngelsdorp 2010) have contributed to a recent interest in bumblebee cultivation to increase crop productivity in fields (McDonough 2011). In addition, indoor greenhouses have used bumblebees for tomato and pepper pollination since the 1980’s. By actively raising bumblebees with artificial nesting sites and sometimes food supplements, growers have been able to save labor of pollinating crops by hand (Winter, Adams et al. 2006). Termed “bombiculture,” this form of insect cultivation is relatively understudied from an ecological perspective. Little is known about how cultivated bumblebees—especially non-native bees—might interact with wild bees. Five species of bumblebees are currently used for commercial crop pollination: *Bombus terrestris*, *B. lucorum*, *B. occidentalis*, *B. ignitus*, and *B. impatiens*. *B. impatiens* (native of North America) and *B. terrestris* (non-native) are the most commonly cultivated (Winter, Adams et al. 2006). The new bees can bring novel parasites or disease. They may compete with native species for forage or nest sites. Finally, they may alter vegetation community composition by effecting the pollination of native and invasive plants (Goulson 2010). If non-native bees are raised or if bombiculture with foreign-bred commercial bumblebee strains are used in the Uwharries, extra care must be taken to understand how these risks effective pollination services and native bee populations.

Other conservation concerns

Land fragmentation (Steffan-Dewenter and Westphal 2008), climate change (New 2009), and invasive species (James and Pitts-Singer) each threaten native bumblebee populations on many scales. While these topics are related to land management, they are

largely beyond the scope of this study. However, they are of such great importance to pollination conservation that they should not be overlooked when making decisions about managing for pollinators.

Bumblebees are particularly vulnerable to diminished population size through land fragmentation because of their social nesting nature, with just one fertile queen per nest (Goulson, Rayner et al. 2011). Breakdown of the metapopulation due to land fragmentation is cited as the main cause for declines in several European species and for extinction in one case (Goulson, Rayner et al. 2011). Land managers can limit fragmentation by reducing sprawling development, by encouraging infill and other conservation-minded city planning measures, and by supporting the establishment of greenways through more densely developed areas (Plath 2004).

Research, largely in Europe, has shown there is a high correlation between pollinating insect diversity, pollination services, and landscape change (Steffan-Dewenter and Westphal 2008). Steffan-Dewenter and Westphal write, “The destruction and fragmentation of natural or semi-natural habitats is expected to cause reduced species richness and abundance as well as changes in species composition of pollinators in these habitats,” and the authors suggest that increasingly intensive agricultural use is an additional but related threat for pollinators (2008).

Human disturbance in the form of fragmentation may significantly reduce native pollinator populations, especially when combined with additional threats from pesticide use, intensive tilling practices, or nutritional deficiencies from foraging on monoculture farms (vanEngelsdorp 2010). However, some research suggests that urban areas can support a greater diversity of pollinators than rural areas (even ecologically-minded farms) due to the diversity of cultivated plants in human population centers (Goulson 2010). That said, conservations generally believe that native vegetation is important for providing nesting sites and other forage requirements for many native pollinators (Natural Resources Conservation Service). Pollination conservation should occur in concert with the diverse goals of holistic conservation efforts to protect the overall health of bee-pollinated ecosystems.

Education for Conservation

Native pollinator conservation is a young and growing field of study, incorporating conservation ecology and public education to protect native pollinators like bumblebees. Education can take the form of citizen science campaigns, community awareness publications, and resources that enable land managers to practice pollination conservation. This project includes education materials for the LandTrust and its partners. The materials use principles of environmental education to: effectively communicate science for broader audiences, to consider ethical foundations for conservation goals and methods in relation to advocacy, and to provide real skills to land managers for immediate habitat improvements.

The Recommendations section above outlines ways the LandTrust can improve management practices on their own properties for pollinator conservation, based on research results of this study and on a literature review of additional research. The methods of the study are easily repeatable with little or no cost, and with little or no damage to ecosystems (particularly if surveying uses photography instead of specimen collecting). Organizations and citizen scientists are encouraged to build from these surveys to improve pollinator monitoring in the Uwharries.

The Appendix provides a Resource List the LandTrust can use and make available to other land managers. Due to the public interest in bee conservation, the recent declines in pollinating animals, and the importance of pollination to both natural and agricultural systems, a wide variety of resources are now available for learning more about native bees. With so much information readily available it can be hard to know where to start. Busy land managers may not want to learn entomological vocabulary just to identify the types of bees on their property, for example. The Resource List serves as an annotated guide to online and printed publications that provide useful information to immediately implement pollination best management practices and to educate children and adults in pollinator education. I focused on bumblebees, but most of these resources are useful for learning about native bees in general. I discovered that children's authors are enthusiastically writing about bees, but not necessarily with conservation education in mind. For environmental educators who may want to entertain kids and still offer

valuable scientific information on this topic, I recommend some age-appropriate kid's books that delve in a little deeper than their silly counterparts. This is not a complete list, but I hope it helps provide a starting point!

Another way for the LandTrust and partner organizations to raise public awareness of pollination conservation techniques in the region is outreach through the media. Appendix D includes two articles written by the author in 2011 for the Montgomery Herald newspaper, simultaneously published online on the University of North Carolina Urban Institute website. These articles translate important scientific information about pollinator conservation into jargon-free prose in the writing style appropriate for feature articles (i.e. with a story). Hopefully these serve to illustrate how ecology can be made more engaging and accessible for the general public.

The purpose of any environmental education activity is dependent on the intended audience, taking into account the audience's age, prior knowledge, motivations, and learning styles (eg. Gardner 1991, Hug 1977). Even political issues are important for environmental educators to understand, as conservation goals may differ according to different demographics (Holsman 2001). Rural development and agricultural productivity may be primary drivers for pollination conservation in some circles, while other community members wish to conserve natural areas to protect wildlife (for hunting or for intrinsic values), or to conserve healthy ecosystems within the context of broader ecological contexts. Nature centers others interested in conservation teach environmental education formally and informally in an effort to change participants' attitudes and actions to be more in line with conservation goals (Hungerford and Volk 1990).

Concepts of successful environmental education were covered in-depth by the "Fundamentals of Environmental Education" class in which the author participated in the fall of 2011. The class (ENV298.40) was taught by Nicolette Cagle at the Nicholas School of the Environment at Duke University. It was based on the Environmental Education and Training Partnership curriculum of the University of Wisconsin-Stevens Point (EETAP 2011). The author gained skills to develop and lead environmental education programs in this class. In addition, she draws on several years of experience as an environmental educator for children and adults with wilderness and sustainable farming organizations.

Four environmental education activities for children are included in Appendix C. They were developed by the author for use by the LandTrust, its partners, and anyone interested in spreading the word about pollinator conservation. The concepts of these activities focus on bumblebee conservation. They are informed by the author's experience and training as an environmental educator and by the scientific research of this study. The activities were designed to be flexible in order to meet the diverse needs of informal and formal environmental educators. For example, several extensions enable the educator to expand the activities if time allows, and suggestions for alternative settings are provided for some activities. The grade levels for activities range from third through twelfth grades, with possibilities for modification for younger learners. The activities are mindful of budget, time, and personnel restrictions at the LandTrust and partner organizations. The format of the activity descriptions follows the Project WET guide (ProjectWET 2011), enabling easy integration into school curriculums. This format includes detailed information on each activity's intended audience, subject areas, topics covered, setting, duration, objectives, teaching methods, materials, and activity procedure.

There have long been different schools of thought regarding the interplay of environmental education, conservation, science, and environmental activism (Hug 1977). To what extent should an environmental educator (formal or informal) teach the ethical motivations behind many conservation goals, and what is the best way to shape a learner's understanding of environmental ethics or issues (Ramsey and Hungerford 1989)? When does advocacy for ecological goals become activism, and are public servants like parks and recreation staff obligated to distance their professional work from advocacy? Such questions are important because they help shape the goals of conservationists and scientists in their education work. The way in which something is taught can dramatically influence the audience's receptivity and response to the information. Ultimately, this shapes land management practice—and bee conservation—on the ground. The objectives of the children's activities presented in Appendix C balance new knowledge (for example threats to bumblebees), skills (for example labeling plant parts), environmental ethics (for example defining intrinsic and utilitarian values), and tools for activism (for example writing persuasively about bumblebee conservation).

The activities provide education for comprehensive conservation related to pollinators, but allow participants to make their own decisions about taking conservation actions.

Other activities the LandTrust and partners should consider are citizen science initiatives like The Great Sunflower Project (www.greatsunflower.org). Facilitators of this project provide seeds for growing bee-friendly sunflowers (*Helianthus sp.*) and encourage groups to do so wherever they live, from urban areas to rural. Then participants are instructed on basic bee identification through online tools and asked to monitor the blooming sunflower in 15-minute sessions. All bee visits are then reported in detail to the online database, where researchers can access extensive and geographically diverse presence/absence and behavioral information on pollinators, helping to follow trends of decline. These hands-on approaches to pollinator conservation utilize an active volunteer base, engaging them in fun outdoor projects or workshops. Citizen science activities are effective educational tools that have been shown to provide invaluable field data for improving bee conservation (Knight, Martin et al. 2005). Such outreach to the general public potentially draws attention to pollination issues, improves best management practices across the Uwharries, and publicly recognizes the achievements of the LandTrust and partners on their pollination conservation successes.

Conclusion

This study is in line with others that have found low abundance and low diversity in bumblebee populations worldwide (for example Colla and Packer 2008, Cameron, Lozier et al. 2011). Because insect pollination is a central component of ecosystem function for both natural and agricultural ecosystems, improved bumblebee conservation is well worth education efforts (Danforth 2007; Kremen, Williams et al. 2007; Mader, Shepherd et al. 2011). Professional conservation ecologists have come a long way toward understanding the effects of habitat alteration on bumblebees and the way this threat interacts with introduced disease, pesticide use, climate, and other factors. The field and laboratory data from this study and others should inform better management practices in the future to protect native pollinating species. No protected area is too small to contribute important resources for pollinators. That said, private and

public landowners and policymakers should work together to halt fragmentation, reduce pesticide use, and to improve conservation efforts on larger scales.

Conservation scientists who aim to spread their message beyond the halls of science can use environmental education for the public as a starting point. Citizen scientists are a valuable asset for conservation, and offer an unparalleled opportunity for educating broader audiences about the specifics of pollinator conservation. By leading educational activities for children, by informing land managers from diverse backgrounds about the ecological and economic benefits of pollination conservation, or by communicating the science of pollination conservation clearly for lay audiences, conservationists can become more involved in ensuring sound conservation practices are implemented throughout communities.

A Note for the Reader

Land managers beginning their conservation efforts for bumblebees and other native pollinators can use a variety of tools to improve their chances of success. The management recommendations of this study provide the basic information needed for attracting and protecting bumblebees to improve pollination for both agricultural and natural ecosystems. Natural areas and gardens of all sizes are important for connecting pollinator conservation efforts across the landscape. There is no alternative for getting your hands dirty. I hope that children and adults alike will take these resources outside with them and begin participating in conservation efforts and citizen science initiatives. Take notes to build on the recommendations here as you figure out what works best for your own pollinator conservation areas. Share what you learn with others as you spread the word about the needs of bumblebees. Happy bee watching!

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Appendices

Appendix A: Survey Site Details

Site Descriptions

The three study sites were located within a 20-mile radius of each other in Montgomery and Randolph counties in central North Carolina. This is the heart of the Uwharrie mountain range within the piedmont region. The landscape is characterized by rolling hills and peaks of moderate elevation. All the study sites are on properties along the Uwharrie River, a Nationally Significant Aquatic Habitat running North to South near the Birkhead Wilderness Area (see “Study Site Locations” Map). They were located in ankle to waist-high vegetation (grasses, forbs, and some trees) (vegetation lists forthcoming). The areas supported deer, rabbits, and other small mammals (including a farmcat and possibly coyotes), turkeys, turtles, snakes, songbirds, birds of prey, and a wide range of insects, with plenty of ticks and chiggers.

Grissom—Restored Prairie Site

This study site was on a privately owned property along Lassiter Mill Road (on the E side of the road) and about 1-2 miles south of High Pines Church Road in Randolph County (see Field 1 in “Restored Prairie” map in Appendix B). This parcel of land includes approximately 2 miles of frontage along the Uwharrie River. This site seemed to have the most bird activity with a wide variety of birds seen and heard during many observation periods. The sites were approximately 375-455 feet above sea level.

The property was burned (?) and planted in native grasses and some wildflowers in April 2006. Land manager John Isenhour describes the planting: “NC Ecotype LBS, BBS and IG [Little Blue Stem, B. Blue Stem, and Indian Grass?], Wildflowers in mix were *Bidens Aristosa*, Narrow-leafed sunflower, Black-eyed Susan and lance-leaf coreopsis” (Isenhour 2011). Since then the property has been burned in spring 2011, and some trees and shrubs were controlled with the herbicide Glyphosate, targeting invasives like tree of heaven (Isenhour 2011).

Transect Locations

“Woods Transect”

The transect ran along the south side of the large field of native warm season grassland, with hardwood forest bordering the transect to the south (on the eastern half of the transect) and with a small extension of the field extending south of the transect’s western half. To the west was Lassiter Mill Road, a paved two-lane road, approximately 5 meters from the start of the transect. The transect was on the south side of a packed dirt path, large enough for ATV use, but apparently unused. It was grown over. Frogs could often be heard from a wetter area in the woods along a tributary. Deer paths crossed the transect and deer were observed once.

“Road Transect”

The transect ran along the west side of the same field, running north to south along Lassiter Mill Rd. Across Lassiter Mill Rd. was mixed hardwoods. Between the transect and the field was a packed dirt path similar to that along the “woods transect”. Between the transect and the paved Lassiter Mill Rd. was a wire fence and then a mowed area of roadside vegetation managed by the road crews. Some areas of this transect were

sprayed with herbicide partially through the summer to control invasive shrubs (Isenhour 2011).

McPherson—Garden Site

The McPherson sites are located on Uwharrie Farm (privately owned), a 120 acre sustainably managed farm in Montgomery County. The McPherson family lives on the property and manages the land for food production and environmental protection. In April 2006 the entire 120 acres were placed under conservation easement with the LandTrust with funding from the Clean Water Management Trust Fund and the Federal Farm and Ranchlands Protection Program. The property includes 8,224 feet of frontage along the Uwharrie River, this part of which is designated by the North Carolina Natural Heritage Program as a Significant Natural Heritage Area. Uwharrie Farm includes mixed hardwood forest in a 100 foot buffer along the river. There is also an unnamed tributary on the property. Much of the property is fescue pasture, which is grazed by two cows. The fields have several copses of hardwoods and shrubs. There are several built structures on the property, including a house, barn, sheds, poultry coops (fewer than 50 birds), and a high tunnel (hoophouse) about 120 by 30 feet. Adjacent to the high tunnel is a mixed vegetable garden of about the same size. The McPhersons use the climate-controlled hoophouse to grow tomatoes for market. They have purchased commercially-reared bumblebee colonies in past years for the indoor tomato pollinating, but have not used them for the last several seasons because they felt wand-pollinating and wind pollination was sufficient and cost effective. A yard of short grass is mowed around the house, and other parts of the property are also mowed but less frequently. Neither transect had been burned in recent history, although an area of scrub brush about 10 meters from the Garden transect was burned in July 2011 (during the study). The sites were approximately 415-475 feet above sea level.

Transect Locations

“Woods Transect”

Located at the SW edge of a mixed hardwood forest stand along a fescue-dominated area of the yard that was mowed a few times throughout the summer. The transect was 200 meters E of a large garage and ran E to W, ending at a cow pasture surrounded by an electric fence. To the S was a small chicken enclosure (about 30x30 meters), and then the garden, high tunnel, and house, all surrounded by mowed grass. The transect had some deer trails and bedding sites (deer were seen in the transect occasionally). The McPherson farm cat was fond of this transect, and some rodent bones were found in it. The 2 steers sometimes observed my research from across their fence.

“Garden Transect”

This transect was positioned in a straight line along an edge of the McPherson’s vegetable garden, then along a clothes line, past a small shed, past the cooling fans of the tomato hoophouse, across an open expanse of the yard, and along the unpaved driveway. Except for the garden beds the transect was frequently-mowed grass, clover, and other typical lawn plants. The transect ran approximately W to E along the S end of the garden and hoophouse, with the McPherson house to the S approximately 20 m away.

Capel—Burned Field Site

This site was on the Capel property in Montgomery County, about 245 acres of which have been owned and managed by the LandTrust since 2009. The sites are on the edges of large fields of native warm season grassland which were the site of prescribed

burns in March 2011. Prior to this burn the fields had been mowed annually for about 40 years. The LandTrust intends to continue burning the sites annually while it owns the property. The sites were approximately 350-400 feet above sea level.

Transect Locations

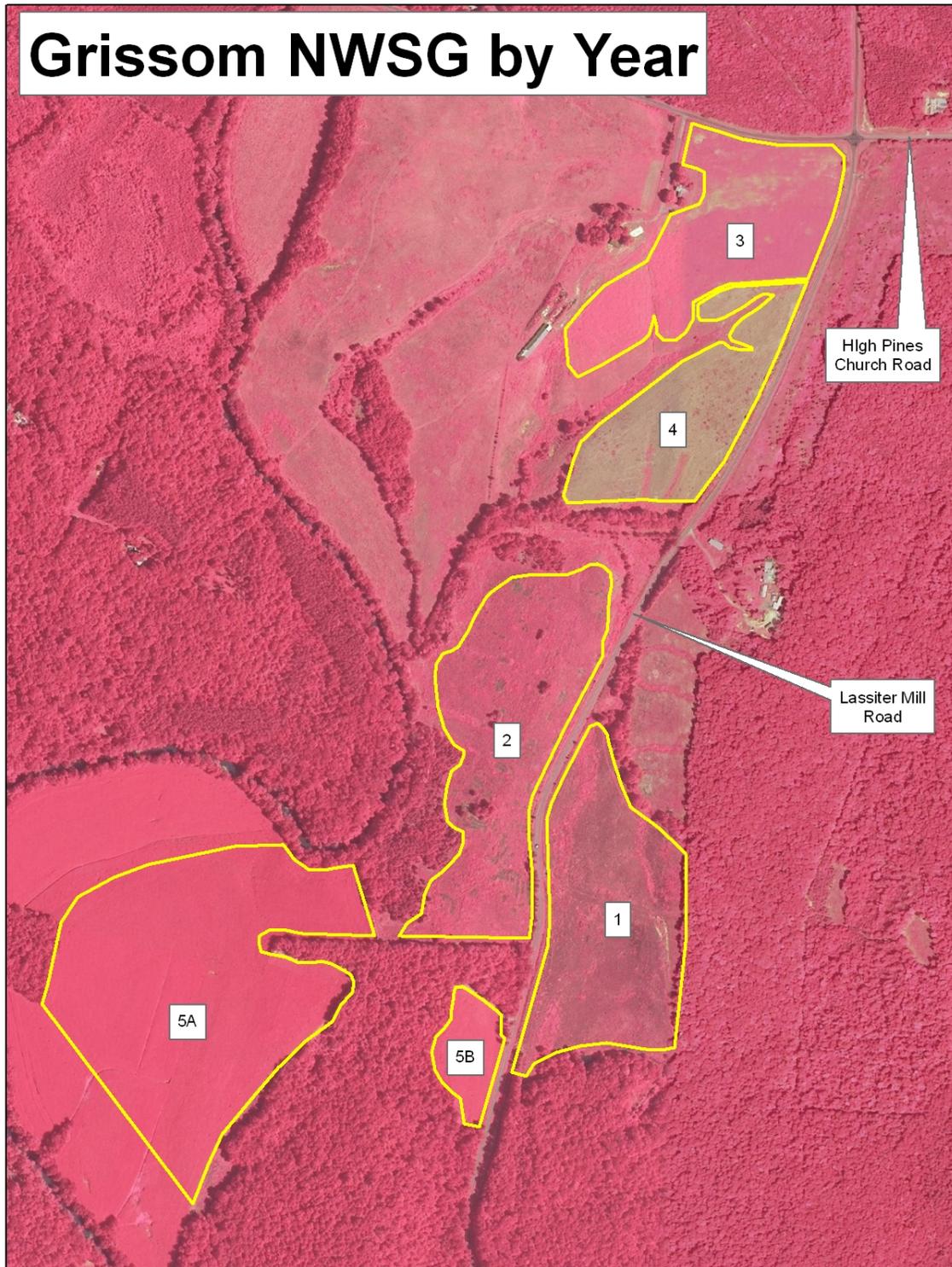
“Upper Transect”

Located along the edge of mixed hardwoods and a large meadow, with the meadow running downhill from the transect. The meadow was surrounded by trees. A packed dirt road ran alongside the transect (between the transect and the woods). Although the path was large enough and seemed used, no ATV traffic was observed directly during the study. The transect began at the corner of the meadow and ended at a large hollowed-out tree.

“Lower Transect”

The transect was at the edge of another meadow, several times larger than that of the Upper transect. Here another packed dirt road separated the transect from mixed hardwoods woodland. The transect included a steep incline and a wetter area at the bottom of the hill, often with standing water on the road here. The transect started just before this dip and went up the hill toward the smaller Upper meadow.

Appendix B. "Restored Prairie" Site Map: Study sites are located along southwest corner of Field 1. An additional transect was studied in Field 5B (Isenhour 2011).



Appendix C. Children’s Educational Activities About Native Pollinators.

First Children’s Activity¹

Pollen Baskets!

A fun way to teach bumblebee conservation,
developed by Dana Powell

Grade Level: Upper Elementary (3-5) (discussion can be modified for younger children)

Subject Areas: Life Science, Ecology

Topics: Bumblebee morphology, behavior, life cycle, and ecology. Bumblebee conservation.

Setting: A large field or lawn, or indoors in a large open room.

Duration: About 1 hour, including prep time (can be easily modified for shorter or longer timeframe).

Objectives: To introduce young children to the habitat requirements of bumblebees, their threats, and to introduce practices of conserving pollinator habitat.

Teaching Methods: Presentation. Whole body game, for large or small group. Discussion.

Materials:

- Large (preferably poster-size) illustration or photograph of a female bumblebee showing pollen baskets on the back legs.

- Bumblebee specimens if available, and hand lens.

- Native wildflowers or pictures of the flowers, if available, especially those favored by bumblebees.

- At least two large bags of white popcorn, enough for each child to have a cup.

- At least two large bags of yellow popcorn, enough for each child to have a cup.

- Three large bowls.

- Eight small bowls.

- Small paper (Dixie) cups; one for each child.

- Construction paper and crayons or markers.

- Tape.

Summary: Participants engage in discussion about native bee habitat requirements and threats. They play a racing game, collecting popcorn “pollen” to bring back to the nest, but unexpected threats make pollen collection more difficult.

Procedure: Preparation: Mix half the white popcorn and half the yellow popcorn in one of the large bowls. Set this bowl on one side of the yard/room, and set 6 of the small bowls several feet away from each other on the same side of the room. Set the other 2 large bowls on the other side of the room. Pin up the bee picture and set out the bee specimens and hand lenses so that everyone can see.

Part 1 (optional): If time allows, introduce a few of the native wildflowers to the group. Have each child draw and color one of the flowers on a piece of construction paper. Tape a flower to each of the small bowls, and any extras to the large bowl of popcorn.

¹ Format modified from Project WET activity guide for teachers (Project WET Foundation 2011).

Part 2: Gather the group around the bumblebee poster (the species should be one found locally). Pass around the bee specimen if available, or have it available on a table up front. Point out on the poster that we know this is an insect because there are six legs and three body parts. Have everyone guess at which insect this is. If they guess incorrectly, point out the important features, for example: “no, a honeybee would be golden-colored without these dark black and yellow stripes, and it would be smaller” or “no, a wasp would have a skinny ‘waist’ and really long back legs”. Point out the area on the bumblebee’s back legs with a scooped-out space surrounded by long hairs. This is the pollen basket. Can anyone see pollen in the picture or on the bees? Explain that pollen comes from flowers, and when it moves from one flower to another it lets the flower grow a seed. The seed is what makes a whole new plant. Bees eat the pollen for food, but they are messy eaters. Some of the pollen gets stuck on their bodies when they fly to one flower and rubs off on the next flower they visit—this is great for the plant! Explain that bumblebees collect pollen from flowers and bring it back to their nest in the grass, where they live all together with many other bumblebees. The adult bumblebees fly out to collect pollen whenever they can so that they can eat some and bring some back for their colony’s babies to eat. To carry a lot of pollen while they fly around the bees put some in their pockets—this area on their back legs called a pollen basket. Explain that today we will play a game to learn how hard it is to be a bee!

Part 3:

Divide the group into two teams, representing two colonies of bumblebees. Each team should sit behind their “nest”. Each child gets a paper cup. Place a few scoops of mixed color popcorn in the small bowls on the other side of the room, explaining that this is the pollen in the flowers and that they will be collecting the pollen in their pollen baskets (cups) to bring back to the nest (large bowl). They can only carry a cupful at a time. The team with the most popcorn (pollen) will win. They can eat the popcorn at the end but not yet! If the group is large, make a rule that only one bee can leave the nest at a time while the others tend the babies. Have the teams get ready and go, and give them 3 minutes to collect as much popcorn as they can. Refill flowers as needed. Stop the teams and regain attention. Say that now unfortunately some of the gardens have been converted to parking lots, and remove some of the flower bowls. If this increases competition discuss how this plays out for bees: if there is a bee already at the flower the others cannot get pollen there. Allow the game to proceed for 3 more minutes. Say that now the nests were damaged in mowing, and take some popcorn out of the big bowls. Allow the game to proceed for 3 more minutes. Say that now we will compare the popcorn, but first, we noticed that there are 2 different colors of popcorn. It turns out that all the yellow popcorn was contaminated with pesticides! These are dangerous for bees, so none of those popcorn kernels count. Have the teams sort out only the yellow kernels (if permitted they may eat these). Now compare the amount of white kernels remaining in the bowls and declare a winner for the round.

Part 4: In this round the procedure is similar, except explain that the nesting habitat has been improved by safer mowing and burning practices and by preservation of excellent grassy areas where bees can nest. There will be no damage to the nest this round! In addition, the community decided to use safer techniques for growing their crops and

gardens without dangerous pesticides. In this round all of the popcorn kernels are white (“pesticide-free”)! Allow the game to proceed for three minutes, then stop and announce that a school group decided to plant a whole garden of native wildflowers to attract pollinators. Increase the number of flower bowls. Allow the game to proceed for as long as time (and popcorn) allows.

Part 5. Debrief the group while they quietly eat the popcorn. Ask whether they liked the game. Ask, “What was the hardest part about being a bee?” As topics come up, discuss how conservation for pollinators can make it easier for the bees to stay safe and get enough to eat so they can do a good job helping the plants make seeds. Ask for the kids ideas about what they would do if they could give any gift to pollinators to make their job easier. Discuss planting flowers, protecting habitat areas, etc.

Extension: Discuss how climate change can make the temperature too hot for some bees to thrive. Add a round in the threats part where kids have to run around the nest 5 times after each pollen load in order to cool the nest off by fanning it with their wings. Do they think this limits how much pollen they could collect?

Second Children's Activity²

Bumblebee Salad

A fun way to teach bumblebee conservation,
developed by Dana Powell

Grade Level: Middle School (5-8) (discussion can be modified for younger or older children)

Subject Areas: Nutrition, Life Science, Ecology, Civics

Topics: Insect pollination. Symbiosis. Plant form and diversity. Human nutrition.

Setting: Indoors (kitchen facilities ideal if enough adult supervision available).

Duration: About 1 hour, including prep time.

Objectives: To introduce students to the concepts of pollination, including symbiosis between flowering plants and pollinating insects. To help students identify the parts of a plant and the botanical origin of foods pollinated by native insects. To teach healthy nutrition and community engagement around food issues.

Teaching Methods: Drawing. Vocabulary building. Scientific inquiry. Cooking. Group work. Discussion.

Materials:

Fruits and vegetables for salad, preferably seasonal (see below for recommendations).

Kitchen materials for prepping vegies: cutting boards and knives, bowls, sink.

Small bowls and forks for serving salad.

Large poster-sized diagram of a flowering plant.

Photographs of growing plants that produce the foods in the salad.

Labels for plant parts (stem, taproot, bud, etc.) and for foods in the salad.

Tape.

Paper, pencils, and colored pencils.

extension:

Markers.

Blank sticker paper (with sticker backing).

Scissors.

Nutrition content for each food.

Summary: Students ultimately prepare a bumblebee salad, comprised of foods that are pollinated by bumblebees or other native pollinators. They work in groups to identify basic plant parts and to identify the botanical origin of common foods. Individually, they draw a detailed diagram of a common food plant. These activities are discussed while preparing the salad in a large group. In the first extension, students study the nutritional content of fruits and vegetables. In the second extension, they create "pollinated by bees" stickers to label bee-pollinated foods in the school cafeteria, and can distribute these in groceries and farmers markets.

Procedure:

Preparation: Collect enough fruits and vegetables for a large salad to be shared by the group. Consider purchasing from local suppliers, or using garden vegetables from a schoolyard garden or local producer. The salad can be traditional veggies, fruit salad, or

² Format modified from Project WET activity guide for teachers (Project WET Foundation 2011).

interesting combinations (try apples and cranberry with spinach). Here are some suggestions (with plant part origin for reference in the activity):

- lettuce (leaf)
- spinach (leaf)
- celery (stem)
- carrot (taproot)
- beet (taproot)
- kohlrabi (stem)
- tomato (fruit)
- apple (fruit)
- orange (fruit)
- dried cranberries (fruit, and stem if sugarcane-infused)
- pecans (seed)
- almonds (seed)
- melon (fruit)
- sunflower seeds (seed)
- broccoli (bud)
- avocado (fruit)
- snowpeas (fruit and seed)
- pepper (fruit)

Make the plant part labels from a simple botanical diagram of a plant (more detailed diagram can be used for older grades). Make food labels (ex. “celery”), one for each food from the salad and any others you like. Hang up the plant poster in an area where everyone can see it. Have both sets of labels nearby. Set up kitchen area with work stations where small groups of students will have close supervision. Set out paper and drawing supplies on tables with enough room for each student.

Part 1: Gather students and tell them they will be making a bumblebee salad today, full of things that bumblebees like to eat. They will get to eat the salad, too! In the following discussion, highlight new **vocabulary** (particularly any scientific vs. common definitions): Ask if they know whether a tomato is a **fruit** or a **vegetable**. If you get both responses, ask for reasons (tastes like a vegetable, juicy like a fruit, etc.) Discuss how **botanists** often have different definitions for plant parts than cooks do. To scientists, a tomato is a fruit because is a fleshy plant part that covers the **seeds** of the tomato plant. Like all fruit, it develops from a **fertilized flower**. Tomatoes and many other plants need bumblebees to fertilize, or **pollinate**, their flowers before the plant makes seeds and fruit. Most people have no idea how many foods they eat are pollinated by wild insects, but today the students will become bee salad experts!

Divide the students into groups of 3 or 4 and distribute the set of plant part labels evenly. Ask the students to decide in their groups where each label should go on the big poster (allow a few minutes). They can then take turns taping up the labels. Make any corrections with the full group’s help and go over the answers once the poster is complete.

Distribute the food labels and have groups attach the food to the part of the plant corresponding to its botanical origin, for example “celery” with the stem.

Discuss how every flowering plant has all the parts in the picture, but they come in different forms. A celery plant has a root, a stem, leaves, and eventually the plant also makes flowers. A sunflower seed tastes good but can also be planted to make a whole new plant with a root, stem, leaves, etc. Once pollinated, flowers produce seeds. Many seeds are covered in a fleshy protective coat called a fruit, which can have many purposes. Some fruits like oranges make thick rinds that keep out mold and bacteria so their seeds don't rot. But the sweet flesh in many fruits (like orange segments) attracts animals to eat the fruit. Why would a plant grow parts that encourage animals to eat them? Animals can distribute the seeds when they drop them or even when they poop, and this lets the plant's seeds grow in many new places—this is good for the plant.

Students can use the paper and colored pencils to draw their own plant and label all the parts. Encourage them to look at photographs of plants that made the salad foods. They might draw an apple tree or a flowering (bolted) head of lettuce, for instance.

Part 2: Make a salad together, using botanical terms while cooking. “Pass me those spinach leaves, please.” “Who will wash this pepper fruit?” Cut an apple across the “equator” and count the seeds in the star-shaped center. If there are fewer than 10 seeds, the apple flower was not visited by enough bees and the fruit may look misshapen (well-pollinated flowers produce the best fruits). When the beautiful salad is finished, applaud everyone's hard work and the hard work of the plants and bees to make it. Enjoy the salad together!

Extension 1: Discuss nutritional content of fruits and vegetables, particularly compared to heavily-processed foods. You may wish to provide nutrition content for the foods in the salad. Discuss calories, “healthy” fats found in foods like nuts, the importance of fiber, and vitamins needed in the human diet. Emphasize the importance of variety. One way to think about this is that eating “colorful” fruits and vegetables helps ensure you are getting all of the diverse vitamins and minerals. Explain that the bees are also interested in eating a good diet when they visit flowers to collect **nectar** and **pollen**. They can't stay healthy if they only eat food from one type of plant, as they must if farmers only plant one crop for miles and miles around where they live. That would be like eating nothing but potato chips all year! But a wide range of flowers in spring, summer, and fall helps give wild bees the food that they need. Farmers who can grow lots of different plants with the bees help also give people the diverse foods they need to thrive.

Extension 2: Pass around sticker paper and pencils. Large sticker paper can be cut down to 3 or 4 inch squares. Have students create “Pollinated by Bees!” stickers. They can add drawings of bees, fruits, and flowers. When the students have careful pencil sketches they can color them with markers. Explain that the students can ask permission to label foods they find that were pollinated by bees, based on the activity. They could ask a farmer at the farmer's market if they could put a sticker near their sign for strawberries, for example. Students can also use the stickers to label each other's lunch bags when they see bee-pollinated foods. Encourage students to discuss what they know about plant parts and pollination with their families at dinner and with others in the community.

Queen For A Day

A fun way to teach bumblebee conservation,
developed by Dana Powell

Grade Level: Middle School (5-8), or may be modified for younger children

Subject Areas: Mathematics, Life Science, Ecology

Topics: Bumblebee life cycle. Ecological effects of land use. Optional: Fractions and fractional area.

Setting: Indoors.

Duration: About 30 minutes, including prep time.

Objectives: To introduce students to ecosystem conservation, focusing on the habitat requirements of pollinating insects. To explore consequences of different forms of human land use and creative solutions for land use compatible with conservation goals.

Teaching Methods: Lecture. Discussion. Conflict resolution. Optional: Mathematical graphing.

Materials:

Blackboard or other large drawing board.

Paper, pencils, and colored pencils.

Graph paper (optional)

Rulers (optional)

Tape

Summary: Students study the lifecycle of the bumblebee, then pretend to be a bumblebee queen by choosing the best nesting location to start her colony from a landscape they create. The landscape incorporates human structures and habitat needs for the bumblebees, demonstrated with drawings that optionally involve mathematical graphing of fractional areas for the different features. Students discover conflicts between some human features and healthy bumblebee habitats. Through discussion, students arrive at creative solutions for conflict resolution to meet human and bee needs. The individual drawings can be taped together to form a map of a conservation landscape.

Procedure:

Preparation: Set out enough drawing supplies for all students, and graphing materials if using.

Part 1: Gather students and tell them they will be bumblebee queens waking up from hibernation! They need to choose a good site to build their nest. Explain the lifecycle of the bumblebee (see Bumblebee Biology section of "Bumblebee Pollination in Central North Carolina" paper for details). Emphasize that bumblebees need open areas with long, clumping grasses or shrubby vegetation to build their nests, and that they have to have lots of areas with flowers within a few miles of their nest to find enough food. They need flower blossoms in the spring, summer, and fall. In the winter, the only bumblebees are over-wintering queens, which hibernate below ground. They need areas with loose, exposed soil that won't be disturbed. They cannot survive in areas with too many pesticides. As you describe these needs, have different student volunteers write the habitat requirements on the board. Create a list of structures or landscape features that

³ Format modified from Project WET activity guide for teachers (Project WET Foundation 2011).

meet the bees' needs (flower garden, forest with undisturbed soil and wildflowers, grassy field, roadside flowers, undisturbed soil on a farm, rooftop garden). Ask students to think about human habitat requirements. Together, make categories (for example: shelter, water, food, and culture). Create a list of structures that meet human habitat needs (house, farm, school, water reservoir).

Part 2. Give each child a large piece of graph paper (or plain paper) and supplies. Ask them to draw a landscape that includes both human and bumblebee habitat. They can add structures that meet one or more needs for one or both species. For the optional graphing component, they should draw structures on the graph paper blocks and calculate the total percentage of the landscape used by each figure. Depending on graph paper size, each square can be a meter. Alternatively, have students pick percentages first for each feature they want to include (adding up to 100) and then fill in the graph paper with appropriately-sized structures. Students should draw a star where they want to locate their bumblebee nest.

Part 3. Tape all the pictures into one large "quilt" to model a complete landscape. Discuss how the landscape could change to support more human and bumblebee habitat needs. For example, houses could be smaller and closer together to fit more people and leave more room for wildlife. Explore other creative options for dual-purpose habitat, such as rooftop gardens or farms that produce food for both bumblebees and people.

Bee Contract

A fun way to teach bumblebee conservation,
developed by Dana Powell

Grade Level: High School (discussion can be modified for younger children)

Subject Areas: Life Science, Ecology, Civics, English

Topics: Pollination services. Bumblebee conservation. Civic engagement. Environmental ethics.

Setting: Indoors.

Duration: About 2 hours, including prep time.

Objectives: To teach students different ways of valuing pollination services, biodiversity, and ecosystem health. To help students engage with differing points of view. To introduce the complexity of environmental ethics, including utilitarian and intrinsic arguments.

Teaching Methods: Lecture. Critical reading. Persuasive writing. Defending a position.

Empathy through role-playing. Group work.

Materials:

Suggested background reading hand-outs or electronic links for students:

Leopold, A. (1988). "Thinking Like a Mountain" *EPA Journal* 14(1):2.

Highlighted Pollination Conservation Sections of the 2008 Farm Bill, extracted by Tom Van Arsdall for the organization Pollinator Partnership, are available at: <http://www.pollinator.org/Resources/PollinatingtheFarmBill,ConferenceReportSummary.pdf>

Importance of Native Pollinators and Bumblebee Biology sections from "Bumblebee Pollination in Central North Carolina" (this report).

Summary: After critically thinking about environmental ethics and utilitarian versus intrinsic values for nature, students write a contract from the perspective of wild pollinators, describing what services they will continue to offer in exchange for adequate protection from human threats. In small groups, students tailor arguments for native bee conservation towards different representatives from society.

Procedure:

Preparation: Assign background ethics readings to students in advance, using these recommendations or anything that provokes thoughtful responses on environmental ethics. To encourage critical thinking, ask them to write out three questions they would ask the authors. Ask them to organize two lists based on the bumblebee information: one labeled "bees provide..." and one labeled "bees need...".

Part 1: Discuss student responses to the readings, emphasizing the concept that there is no single environmental ethic that can be "prescriptive". Discuss issues of intrinsic versus utilitarian values for pollinating insects, and have students reevaluate their lists. Did they

⁴ Format modified from Project WET activity guide for teachers (Project WET Foundation 2011).

include any intrinsic values? Why or why not? Students will write from another's voice in this activity. From the perspective of native bumblebees, each student should write a "legal contract" stating what they will continue to offer humanity in exchange for adequate protection from human threats. Topics covered may include bee pollination services for farms, healthy vegetative communities that support additional ecosystem services for people, and biodiversity, all provided in exchange for enough forage and nesting habitat and freedom from imported disease and pesticides.

Part 2. Next, students must convince other people to sign on to the contract. In small groups, students should compare the items on their contracts and come up with the best way to "pitch" the contract to two of the following: the town mayor, the director of a nature preserve, a large corn farmer, a small "pick your own" farmer with a variety of crops, a suburban home owner, the grounds keepers at their high school, an elementary school science teacher, or a restaurant owner. Encourage students to think creatively to incorporate more utilitarian and more intrinsic values for bees into their arguments.

Extension: Hold a town meeting to discuss which items should be in the bee contract, with one group representing the bees and other groups representing some of the individuals from Part 2.

Appendix D. Examples of two articles for local newspaper
Published in *Montgomery Herald*, Outdoors Column August 2011.

Native Pollinators

Dana Powell, LandTrust for Central North Carolina



Bombus sp. Photo by Dana Powell.

Fruits and vegetables that taste like summer—tomatoes, peppers, cucumbers, blueberries, raspberries, melons—are swelling and ripen in gardens and farms of our region. These crops would be far less abundant without the buzzing chorus of pollinating insects that provide their services for free.

Commercial honey bee and bumble bee operations make good use of the industrious *Apidae* species. Bumble bee pollination alone is worth \$15 billion to greenhouse tomato growers, for example. But wild bees, butterflies, beetles, flies, and even birds and mammals all contribute to the flowers, fruits, and seeds we enjoy. Some 35 percent of our food crops depend on insect pollination. Natural ecosystems also rely on the pollination services at the heart of the food chain. A plump, well-pollinated mulberry might be a tasty snack for a hiker, but good fruit set is essential for wildlife like black bears that need large energy reserves to survive the winter.

The story linking flowering plants and insects goes back millennia. Before there were any flowers in the world only wind pollinated plants like pines grew. Then some plants evolved a handy trade-off system with hungry insects. By offering caloric nectar and pollen, advertised with scented, showy, come-and-get-it flowers, the plants got a pollen taxi to carry their genes from one flower to another to make new seeds.

One of the most promiscuous native pollinators this time of year is the boisterous bumble bee. These (relatively) large, hairy beasts are hearty enough to fly even in the rain. They pollinate a host of native and cultivated plants thanks to the furry down that catches pollen at each flower visit. Unlike their foreign honeybee cousins, bumble bees can “buzz pollinate” plants like those in the tomato family, vibrating the flower parts in just the right way for pollination success. Slow to sting and fast flying, bumble bees are welcome and effective pollinators.

Native bees and other local pollinators need advocates who are willing to take extra precautions with pesticides. As Colony Collapse Disorder threatens honeybees, it is in our best interest to pay special attention to the needs of pollinating species. Native bees need undisturbed natural areas to forage and nest in all year long. Many species nest underground in old rodent dens, or burrow in small holes in logs. You can attract helpful insects to your own garden by supporting land conservation efforts in your neighborhood and by leaving plenty of natural nesting and foraging areas on your property. To find out how to choose native plants our local pollinators love and even how to supply nesting boxes for native bees, check out this [information](#) from the Xerces Society for Invertebrate Conservation.

Article for *Montgomery Herald Outdoors* Column:

Citizen Science

Dana Powell, LandTrust for Central North Carolina

Have you wondered if bees in our area are suffering from Colony Collapse Disorder? Do you know what fly fishing's aquatic insects can tell us about water quality? Entomologists (insect scientists) are no longer the only people watching bugs. Like many branches of natural science, entomology has reached out to citizen scientists to get help in understanding the world around us.

A citizen scientist might be a grade school student measuring water temperature in a stream near her school. Or a hobbyist may have detailed notes on the birds visiting his backyard feeder. Their individual observations are compiled into large online databases. These treasure troves of information provide researchers with detailed data from across a whole region or continent.

One of the most pressing questions citizen scientists are tackling today is the decline in bee populations around the world. Beekeeper reports show that honeybees declined again last year by 30 percent, but the causes are still not fully understood. Scientists have struggled to record even basic observations on where and how other bees are threatened. The Great Sunflower Project is one of several citizen scientist movements that aim to improve bee monitoring. Participants plant sunflowers in backyards or balconies and spend 15 minutes watching the flowers for pollinating bees. They report bee visits online, where research teams can use the data to map bee populations across the country. Similar projects have incited backyard birders to track threatened species, with some data sets going back centuries to the early birding societies in Europe.

For citizen scientists who prefer exploring our waterways, The North Carolina Department of Environment and Natural Resources Division of Water Resources coordinates aquatic programs like Stream Watch. Participants monitor water quality of adopted streams, reporting problems such as garbage dumping. They learn to identify aquatic organisms that signify different pollution levels. Stream Watchers are encouraged to become more involved in cleaning their stream and advocating for its protection. Often participants live or work near the stream they adopt. The program benefits stream health by fostering local support for cleaner water and by rounding up new scientific data from the people nearest the source.

People who participate in citizen science projects in entomology and other fields might learn about storm drain systems, bird migration, or insect lifecycles. They also learn to engage with the living, breathing world in a way that can't be taught remotely. Exploring the world directly teaches new perspectives that are increasingly important in a changing environment. Where would we be without the basic understanding of ecosystems that keep our drinking water drinkable and our farms productive? This knowledge is too important for a small group of professionals to carry alone. Citizen science shows us that environmental literacy can be a more universal goal.

If you want to pick up a clipboard and join in the fun:

The Great Sunflower Project for bee monitoring: <http://www.greatsunflower.org/>

Stream Watch for aquatic monitoring:

http://www.ncwater.org/Education_and_Technical_Assistance/Stream_Watch/

Appendix E. Resource Guide for Native Bee Conservation

Bumblebee Biology, Ecology, and Conservation Books:
Selected from literature review of bumblebee conservation topics.

The humble-bee : its life-history and how to domesticate it

Bombiculture, or bumblebee keeping, is now practiced commercially. One of its earliest practitioners wrote an influential guide to bumblebee rearing that offers a fun and informative background section on bumblebee life history.

Sladen, F. W. L. (1912). The humble-bee : its life-history and how to domesticate it, with descriptions of all the British species of *Bombus* and *Psithyrus*, London : Macmillan.

Bumblebees and Their Ways

Another classic text in the study of bumblebees, Plath provided an important early account of studying the *Bombus* (bumblebee) genus and their close relatives, the cuckoo bees.

Plath, O. E. (1934). Bumblebees and their ways. New York, The Macmillan Company.

Attracting Native Pollinators

Offers the most recent, practical information for land managers aiming to provide the best native pollinator habitat possible in a variety of settings, from urban schoolyards to large production farms. Comprehensive, clear, and well-researched. This guide also offers the best basic bee identification guide with color photos.

Mader, E. (2011). Protecting Native Pollinators, Pittsboro, NC, Xerces Society for Invertebrate Conservation.

The natural history of bumblebees : a sourcebook for investigations: a sourcebook for investigations

This slender volume offers a handy pocket reference with color photos for species identification (although in limited poses), along with thorough background information that explains bumblebee life cycles, behavior, conservation, and other topics. Strong science without scientific jargon.

Kearns, C. A. and J. D. Thomson (2001). The natural history of bumblebees : a sourcebook for investigations: a sourcebook for investigations. Boulder, University Press of Colorado.

Bee pollination in agricultural ecosystems

Farmers are leading the conservation efforts for native bees in many areas, and thanks to their ability to offer important bee habitat. Pollination services are an important resource for all of us. This book helps managers understand the science of pollination and the ways in which agricultural land use influences pollinators.

Pitts-Singer, T. L. and R. R. James (2008). Bee pollination in agricultural ecosystems. Oxford, Oxford University Press.

Pollination ecology : a practical approach

For those interested in studying bumblebees scientifically this book provides a good introduction to the techniques needed for field studies in pollination ecology. This would be a good starting point for enthusiastic citizen scientists or conservationists ready to design their own bumblebee survey.

Dafni, A. (1992). Pollination ecology : a practical approach: a practical approach. New York, IRL Press at Oxford University Press.

The conservation of bees

Bee conservation has grown as a field internationally, particularly as global pollinating species have declined. This book draws from studies mostly in Europe, North America, and Asia to provide a solid overview of the status of bees as we understand them.

Includes many types of wild bees.

Matheson, A., L. Linnean Society of, et al. (1996). The conservation of bees. London, Academic Press.

Insect conservation : a handbook of approaches and methods

Invertebrates are not commonly considered in wildlife management programs, but recently interest in protecting insect species has grown. This volume introduces some of the management tools used in mostly species-specific conservation practices, which could be applied to conserving rare bumblebee species.

Samways, M. J., M. A. McGeoch, et al. (2010). Insect conservation : a handbook of approaches and methods: a handbook of approaches and methods. Oxford, Oxford University Press.

Children's Books:

Selected based on book content from the "Novelist K-8" database:

<http://www.ebscohost.com/novelist>

Summaries and age ranges provided by the database.

Bumblebee

By: Wilson, J. V. (Sep 2011) Frances Lincoln Children's Books

Describes the life cycle of the bumblebee.

Ages 9-12 Nonfiction

Bumblebees

By: Van Dyck, Sara (May 2005) Lerner Publications

Describes the life cycle of bumblebees and discusses their relationship with flowers and with people.

Series: Early bird nature books

Ages 9-12 Nonfiction

Buzzing bumblebees

By: Riley, Joelle (Feb 2003) Lerner Publications

Introduces anatomy, behavior, and homes of bumblebees.

Series: Pull ahead books, Animals
Pull ahead books
Ages 0-8 Nonfiction

The bumblebee queen

By: Sayre, April Pulley (Feb 2005) Charlesbridge Publishing
Discusses the life cycle of a bumblebee queen, following her from the time she digs out of the ground in the spring to the next seasons cold weather.
Ages 0-8 Nonfiction

Bumble bees

By: Howard, Fran (Jan 2005) Capstone Press (MN)
Simple text and photographs describe the physical characteristics of bumblebees.
Series: Pebble plus: bugs, bugs, bugs!
Ages 0-8 Nonfiction

The humblebee hunter: inspired by the life & experiments of Charles Darwin and his children

By: Hopkinson, Deborah (Feb 2010) Hyperion Book CH
On a beautiful day, some of Charles Darwin's many children help him study humblebees (bumblebees) in the garden at their home in the English countryside.
Ages 0-8 Fiction

Bees

By: Jango-Cohen, Judith (Feb 2007) Marshall Cavendish
"Describes the physical characteristics, behavior, and habitat of bees"--Provided by publisher.
Series: Animals, animals
Ages 9-12 Nonfiction

Jam and honey

By: Morales, Melita (Jan 2011) Tricycle Press
Tells the story of a young girl and a honeybee who learn to coexist peacefully in the same garden as they go about their respective tasks.
Ages 0-8 Fiction

What is pollination?

By: Kalman, Bobbie (Sep 2010) Crabtree Publishing Company
Introduces pollination, describing how it is carried out, the insects and other types of animals who act as pollinators, and the threats to the survival of these pollinators, including diseases and pesticides.
Series: Big science ideas
Ages 9-12 Nonfiction

Wildflowers around the year

By: Ryden, Hope (Mar 2001) Clarion Books

Describes how wildflowers survive with the help of birds and insects, and explains where each example is found and how it grows.

Ages 9-12 Nonfiction

Internet Resources:

The Xerces Society for Invertebrate Conservation is a nonprofit organization that has successfully advocated for protection of invertebrate species in the US. In addition to supporting native pollinator species they are interested in protecting pollination services more broadly. They have several full-time staff working exclusively on pollination issues. Their online Pollinator Resource Center offers the most comprehensive tools to pollinator conservation I have found. For basic information on native bee declines, bumblebee identification, the how-to's of preserving bee habitat, and other practical basics, I would start here. Of special note is the Pollinator Habitat Assessment Form and Guide for farms (PDF) and the Pollinator Habitat Assessment Form and Guide for organic farms (PDF), which can be printed for use in the field to determine which pollinator habitat characteristics are already being met by the farm, and which areas of the farm can be improved.

<http://www.xerces.org/pollinator-conservation/>

“Native Plants for Bee Forage”

Compiled by Debbie Roos, North Carolina Cooperative Extension

A local extension office (Chatham County, NC) created a resource list for pollinator information geared toward small gardeners. The office also provides recommendations for pollinator gardens specifically in central North Carolina:

<http://www.ces.ncsu.edu/chatham/ag/SustAg/pollinatorresources.html>

Pollinator Partnership is a nonprofit organization working to protect native pollinating animals in North America. They offer science-based conservation information and community participation tools to help foster successful pollination conservation.

Resources available on their website include a smartphone app for selecting pollinator-friendly native plants, factsheets about pollination needs for everyone from hunters to golfers, and organizer resources for an annual Pollinator Week. Their website is:

<http://www.pollinator.org>

North American Pollinator Protection Campaign (NAPPC), administered by the Pollination Partnership, is an international organization of more than 100 partners in science, government, and conservation. They focus on the conservation of pollination services and pollinator species. Their next conference will be held in October 2012 in Virginia. Their website is:

<http://pollinator.org/nappc>

Pollination Curriculum offered by NAPPC for students in 3rd-6th grade. The curriculum allows teachers to introduce their students to basic pollination biology,

pollinator ecology, and hands-on experiences with pollination conservation. The curriculum can be found at:

<http://www.pollinator.org/nappc/PDFs/curriculum.pdf>

US Fish and Wildlife is interested in pollination conservation as it relates to education and connecting people with nature, and for conserving pollination services for endangered plants and animals as well as for people. They introduce their involvement with pollination conservation here:

<http://www.fws.gov/Pollinators/pdfs/PollinatorNew030508.pdf>

The US Department of Agriculture and partners provide a guide to the voluntary-participation programs of the Farm Bill that can be used to fund pollination conservation. For example, the Environmental Quality Incentives Program offers land owners up to 75% cost share and other economic incentives for implementing conservation practices, particularly those that enhance pollinator habitat. The guide to using these types of programs can be found at:

http://plants.usda.gov/pollinators/Using_Farm_Bill_Programs_for_Pollinator_Conservation.pdf

The Farm Bill itself contains language with a new focus on pollination conservation. The entire 2008 Farm Bill and updates for the 2012 Farm Bill can be found at:

<http://www.usda.gov/wps/portal/usda/farmbill2008?navid=FARMBILL2008>

Highlighted Pollination Conservation Sections of the 2008 Farm Bill, extracted by Tom Van Arsdall for the organization Pollinator Partnership, are available at: <http://www.pollinator.org/Resources/PollinatingtheFarmBill,ConferenceReportSummary.pdf>