ABSTRACT

Title of Document: CONSERVING POLLINATORS: AN INTERDISCIPLINARY APPROACH TO EVALUATING THE ECOLOGICAL, ECONOMIC AND CULTURAL VALUE OF NATIVE BEES IN MID-ATLANTIC SUSTAINABLE AGRICULTURE

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Certain pollinator populations are threatened globally due to habitat fragmentation and alteration, pesticides, disease and infestations by parasites. Localized population declines have prompted interest on the part of various stakeholders in restoring and maintaining pollinator-friendly habitats on working landscapes, particularly private agricultural lands. Recommendations from the National Research Council's report, *Status of Pollinators in North America*, include informing the agricultural community about ways to manage pollinators and conducting studies to improve restoration protocols and to understand land managers' willingness to adopt pollinator-friendly practices (NRC 2007). Interdisciplinary in nature, this research follows NRC's recommendations and incorporates methods from environmental science, ecology and anthropology to investigate and evaluate the opportunities and challenges to native bee conservation in

Mid-Atlantic sustainable agriculture. I censused sustainable agriculture farms to assess the diversity of bees in different habitats and collected and identified over 3100 individuals representing five families, 26 genera and 81 species. Native bee abundance measures indicated a temporal shift in foraging among habitats with more bees moving into crops in mid-summer. I investigated floral constancy and visitation rates among native bees at Blandy Experimental Farm in Boyce, VA and found that bees move primarily among conspecific flowers and that particular flowers are more attractive to certain bee genera. I also investigated pollination of okra (*Abelmoschus esculentus*) and bell pepper (*Capsicum annuum*) and examined importance of native bees to Mid-Atlantic vegetable crops. Additionally, I conducted a survey to examine similarities and differences in beliefs and values of Mid-Atlantic sustainable agriculture producers and pollinator scientists/managers in relation to native bee conservation. Sustainable agriculture farmers already hold beliefs, values and knowledge about ecosystem services conservation; therefore to formulate effective outreach, there is a need to understand how these beliefs differ or align with those of pollinator advocates. Although sustainable agriculture producers and pollinator scientists/managers share certain beliefs and values, enough differences were detected to impact outreach efforts. Results from the research can be used to develop feasible conservation approaches for native bees in this region.

CONSERVING POLLINATORS: AN INTERDISCIPLINARY APPROACH TO EVALUATING THE ECOLOGICAL, ECONOMIC AND CULTURAL VALUE OF NATIVE BEES IN MID-ATLANTIC SUSTAINABLE AGRICULTURE

By

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Dedication

For my Dad, Jack Meredith, whose memory inspires me to learn new things at any age

Also for Joseph Katsouros, fellow PhD student in Physics at University of Maryland,
a life taken away much too early

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Chapter 1: Introduction and Purpose of Dissertation

Introduction

In November 2006, a Pennsylvania beekeeper reported massive die-offs in his honey bee (*Apis mellifera*) colonies that were overwintering in Florida. Soon after, several other beekeepers came forward with a similar problem of major losses in managed honey bee colonies. The unexplained phenomenon was categorized by apicultural scientists as Colony Collapse Disorder (CCD) and has since been experienced by beekeeping operations across the United States with losses amounting to more than 2.4 million colonies with a projected US$8 to US$12 billion economic impact. The decline in honey bees is especially worrisome for farmers who rent honey bee colonies in order to pollinate crops such as apples, citrus, almonds, blueberry, cucumber and watermelon, to name a few. Without an adequate number of bees to move pollen from flower to flower, crop yields drop in quality and number with the dire consequence of loss in revenue.

In the United States alone, over 150 food and fiber crops estimated at more than US$20 billion in annual revenue rely on the ecosystem service provided by pollinators, primarily managed honey bees, in their production (Kevan 1991). The cost of lost pollinator services is substantial in some markets (Kevan & Phillips 2001). Lowbush blueberry production in New Brunswick dropped off due to pollinator declines (Belaoussoff & Kevan 1998) and detrimentally affected the local economy. A more recent example involves almond orchards in California. It is predicted that California's almond industry could suffer substantial economic losses due to a lack of honey bee pollination and the high cost of renting what limited colonies are available (Souza 2005).

Declines in pollination services raise important questions about how the United States agricultural system impacts ecosystem services, the very same services that agriculture requires for sustainability and profitability. Unsustainable practices can damage our access to ecosystem services; for example, pesticide applications can negatively affect bees that pollinate important food and fiber crops. Reliance solely on honey bees for pollination services could prove to be unwise if CCD and other colony disruptors such as pesticide misuse, disease and loss of foraging habitats are not mitigated. In the meantime, it is important to look for alternative methods for getting crop pollination needs met. One plausible alternative is the shift to incorporating native unmanaged pollinators into crop production in order to supplement the efforts of the overworked honey bee.

Purpose of dissertation

In light of the recent disruption in many commercially managed honey bee colonies, more research is warranted to investigate how other bee species can supplement pollination for some farms. The National Research Council published a report, entitled *Status of Pollinators in North America*, that outlined gaps in knowledge about pollinator decline, potential implications of species loss and recommendations for rectifying the situation including expanding research on native pollinators (NRC 2007). I chose to investigate the opportunities and challenges associated with increasing the use of the alternative pollinators, namely non-*Apis*, in sustainable agriculture in the Mid-Atlantic. For purposes of this research, I have defined the Mid-Atlantic region using the Environmental Protection Agency's Region 3 Mid-Atlantic designation of Delaware, District of Columbia, Maryland, Pennsylvania, Virginia and West Virginia. Due to the complexities that envelop the topic, I selected an interdisciplinary approach to guide me so that I could incorporate methods from several disciplines to help explain the ecological, economic and cultural value of native bees and the ecosystem services that their habitats provide for small operations that emphasize sustainable practices in the production of marketable goods.

The importance of the honey bee, the most managed and recognized crop pollinator, is easier to evaluate than that of unmanaged native pollinators primarily because studies in apiculture have a much longer history. More research is required to quantify the habitat requirements of native bees, their pollination efficiencies and the factors that influence the adoption of management practices that promote their conservation. Even though the National Research Council's report outlines several recommendations for native bee management on working lands, several questions remain unanswered in regard to native bee biology, ecology, economic importance and implementation of pollinator-friendly practices in agriculture. Table 1.1 lists several important gaps in research. Answering these questions requires an integrated approach that incorporates methods from diverse disciplines. Answers to these questions all combine to inform the value of native bees in agriculture. Understanding the ecological, economic and cultural value of native bees is essential for conservation of these species. Without tools to value native bees and their importance in agriculture, protection efforts most likely will be overlooked in favor of other priorities.

Table 1.1. Important research gaps.
Listed are the gaps in knowledge that need to be addressed in order to carry out the recommendations in the NRC report, *Status of Pollinators in North America.*

- What pollinators are present on farms and in what quantities?
- Which pollinators pollinate which crops and by how much?
- How can farmers attract pollinators to farms and get them to pollinate crops?
- What habitats are required to sustain pollinator populations on farms?
- What are the economic costs and benefits of maintaining pollinator populations on farms and how can they be calculated?
- What outreach approaches and incentives will work best to involve farmers in pollinator conservation?
- Will pollinator conservation be difficult due to bee myths and fears?
- Are pollinator advocates "preaching to the choir" by approaching sustainable agriculture farmers with pollinator conservation outreach?

Almost all of the recommendations from the NRC report for conserving native pollinators (see Table 1.2) call for actions that require knowledge from multiple disciplines in addition to pollination ecology (NRC 2007). Two of the NRC report recommendations are highlighted here to demonstrate how interdisciplinary research is necessary to discover the appropriate means for carrying out these actions. In reference to the first recommendation listed in Table 1.2, "inform[ing] the public, in particular, the agricultural community," is achieved in many different ways, some more successful than others. For example, Community Supported Agriculture (CSA) farmers in the Northeast rely on other farmers for new information and rarely contact extension agents (Worden 2004). Understanding the ways in which people obtain information is a crucial component of a successful conservation strategy for pollinators. Additionally, "actions (such as creating pollinator habitats) that can be taken to manage pollinators" can differ greatly from region to region. It is necessary to understand pollinator communities and cultural communities at the same time in order to execute the first recommendation. As recommended in Table 1.2, to "conduct additional studies that can be used to improve existing restoration protocols, including monitoring the influence of restoration activities on population and community dynamics of pollinators," and "understanding land manager's willingness to adopt restoration practices," multiple disciplines must be tapped for methods that can be used to obtain the sought after data. The individual research questions within the dissertation help address some of the gaps in knowledge that need to be considered in order to implement actions recommended by the NRC study.

Table 1.2. Recommendations for native bee management from NRC report.

1.	Inform public—in particular, the agricultural community, managers of golf courses, urban parks, and other large urban-suburban areas such as industrial and academic campuses—about current knowledge on actions (such as creating pollinator habitat) that can be taken to manage pollinators.
2.	Conduct field studies in different regions of North America to determine the suites of key floral resources for use in restoration protocols in each region.
3.	Conduct additional studies that can be used to improve existing restoration protocols, including monitoring the influence of restoration activities on population and community dynamics of pollinators and understanding land managers' willingness to adopt restoration practices.
4.	Define land-management practices (by NRCS state offices) that encourage pollinator populations that are eligible for federal payments under existing farm bill conservation programs such as EQIP, WHIP, CRP, and CSP.
5.	Integrate land-management practices that encourage pollinator populations at the state level into existing Farm Bill conservation programs such as EQIP, WHIP, CRP and CSP.
6.	Conserve existing natural habitats in human-dominated landscapes.

(NRC 2007)

Justification for conserving native bees in Mid-Atlantic sustainable agriculture rests on the premise that benefits of establishing pollinator-friendly practices on farms outweigh challenges to their implementation. A critical evaluation of current incentives and barriers is necessary in order to develop a comprehensive approach to native bee conservation in agricultural landscapes. By using sustainable agriculture in the Mid-Atlantic region as a case study, this research provides a template for future interdisciplinary projects that attempt to answer similar questions for other agricultural systems or locales. Researchers, resource managers and landowners from other regions can gain understanding from the lessons learned in this region. As stated above, my research focuses on sustainable agriculture farms in the Mid-Atlantic, yet conventional farms should not be excluded from efforts to restore and maintain natural pollinator populations, especially commercial vegetable operations. This research project provides a starting place from which future projects that address pollinator conservation on conventional farms can obtain recommendations developed from the lessons learned in this study on sustainable agriculture farms.

The dissertation is divided into seven remaining chapters following this introductory chapter. Chapter 2 provides background on native bees, their habitats and the pollination services they supply. In this chapter, I also describe pollinator decline in more detail and review conservation efforts to date. In Chapter 3, I introduce the Mid-Atlantic region and illustrate the suitability of sustainable agriculture to native bee conservation, enhancement and service. Chapter 4 details my interdisciplinary approach by offering the rationale for expanding the research into multiple disciplines to address the ecological, economic and cultural significance of native bees. Chapter 5 addresses biodiversity values attributed to native bees by describing experiments that investigate diversity measures and habitat use in sustainable agriculture. Chapter 6 considers the pollination services of native bees in Mid-Atlantic sustainable agriculture. In Chapter 7, I address the cultural significance of native bees by describing the findings from interviews and a survey intended to elicit farmers' and scientists' perceptions about the importance of pollinators and their conservation. Finally, in Chapter 8 I review the findings from the previous chapters and develop recommendations for native bee conservation and utilization in Mid-Atlantic sustainable agriculture and beyond.

Chapter 2: Overview of the Importance of Native Bees

Pollinators are animals that move pollen from one plant to another of the same species. Most commonly, animals from several taxa within the classes Mammalia, Aves and Insecta perform pollination. Examples of mammal pollinators include bats, rodents and monkeys. Hummingbirds are the most discernible bird pollinators in North America, although there are many others. Insects constitute the largest group of pollinators. The insect orders involved in pollination are Hymenoptera, Lepidoptera, Diptera, Coleoptera and Thysanoptera. Probably the most recognized pollinators are bees and in particular honey bees (*Apis mellifera)*.

For millennia, human beings have enjoyed the presence of pollinators for the sake of their beauty, their behavior and their evolutionary wonder. Human curiosity is piqued by the social structure of a honey bee colony or the incredible velocity of the hummingbird's fluttering wings. Pollinators appear in numerous depictions through time as symbols of wealth, health, fertility and security (Bishop 2005). It is probably no coincidence that the "birds and the bees," the ones that help plants to reproduce, have made their way into colloquial language.

The myth and mystery that surround pollinator species contribute to their cultural value. The function of pollination is described as early as 350 BC by Aristotle and has appeared in paintings and sculpture for centuries since then (Mayhew 1999). Modern day marketers incorporate pollinators on their products. Burt's Bees, a company with annual sales in excess of US$110 million, sells "earth-friendly, natural personal care products" using bee-related metaphors throughout their website and packaging such as their Body

Nectar Softening Set accompanied by the sales pitch of "Honey, this set is amazing!" While pollinators elicit notions of good health, some pollinators, especially bees, provoke feelings of apprehension. With the help of popular media and moviemaking, Africanized bees strike fear into unwitting people (Winston 1992).

Honey bees are not native to the United States. They were introduced around 400 years ago by Europeans for purposes of pollination of agricultural crops and honey production. The honey bee generates economic profit for the beekeeper directly through honey and wax production and hive rental. Beekeepers often rent their honey bee hives to growers so that orchards or row crops receive adequate pollination. An important distinction is made among nonnative managed honey bees that are social and live in either natural or human-constructed hives, nonnative unmanaged feral honey bees, native managed bees and native wild bees, the majority of which are solitary and nest alone in hollow stems, bark, dead wood, or ground nests (Michener 2000). Native managed bees such as alkali bees (*Nomia melanderi*), orchard mason bees (*Osmia* spp.) and bumble bees (*Bombus* spp.) can be partly managed by providing nesting materials although the intensity of management is far less than that of honey bee hive management (Table 2.1). For purposes of this research, the term *native bees* refers to native wild bees that use habitats on agricultural lands but are not necessarily targeted for management by the grower.

Table 2.1. Distinction between native, non-native, managed and unmanaged bees.

Bee	Origin		High to mid management		Minimal to no management		
	Native	Non-native	Hive boxes	Nest boxes/substrate	Floral resources	Natural nest habitat	Reduced pesticides
Apis mellifera (European honey bee)		X	X		X		X
Nomia melanderi (alkali bee)	X			X	X		X
Osmia spp. (orchard mason bee)	X			X	X		X
Bombus spp. (bumble bee)	X	X[1]		X	X		X
Megachile rotundata (alfalfa leafcutter bee)		X		X	X		
Family Halictidae (sweat bees)	X				X	X	X
Family Andrenidae (miner bees)	X				X	X	X
Xylocopa spp. and *Ceratina* spp. (carpenter bee)	X				X	X	X
Peponapis pruinosa (squash bee)	X				X	X	X
Family Colletidae (plasterer bee)	X				X	X	X

[1]Imported bumble bees

A process that is critical to the successful reproduction of seed-producing plants, pollination is the transfer of male gametes, in the form of pollen grains, to the receptive part of the carpel that houses the female gametes, in the form of ovules. Pollination occurs via several forms. Hydrophily is the transfer of pollen by water, anemophily by wind, zoophily by vertebrate animals and entomophily by way of insects. Gymnosperms, such as cone-bearing conifers, rely heavily on wind pollination whereas many of the angiosperms, the flowering fruit-bearing plants, require an animal pollinator to help in the transfer of the male gamete to its female counterpart. Depending on the species, some wild and cultivated plants can be completely dependent on animal pollinators for their reproduction while others show increased yield or quality if visited by animal pollinators (Klein *et al.* 2007; Ricketts *et al.* 2004).

Over the last decade, several publications include pollination as one of the most important ecosystem services to human viability (Allen-Wardell *et al.* 1998; Eardley

2000; Heard 2001; Kevan & Phillips 2001; Klein *et al.* 2007; Watanabe 1994). In exchange for their pollination services, pollinators receive sugar-rich nectar and/or protein-rich pollen (Goulson 2000; Westphal *et al.* 2003). Pollinators ensure that plant populations retain their genetic variability by moving genes away from their source to alternate recipients. Genetic variability provides a safety mechanism of resilience in the face of disease for both pollinator and plant host species and is one of the benefits of the coevolved mutualisms between pollinators and flowering plants (Kearns *et al.* 1998).

Wild and cultivated plants alike benefit from pollination services and hundreds of cultivars would not be available for human consumption if pollinators did not transfer pollen from one plant to another (Klein *et al.* 2007). Additionally, because pollinator populations are variable, a diversity of pollinators ensures that at any one time one or more species are available to pollinate crops (Kremen *et al.* 2002). Maintaining native bee habitats can aid vegetable growers who employ managed honey bees since native bees supplement pollination either directly by visiting flowers or by inducing honey bees to increase their floral visitation rates in order to avoid interaction with native bees on the same flower (Greenleaf & Kremen 2006b). For those farmers without access to managed bees, native bees do much of the pollination for those crops that require it (Greenleaf & Kremen 2006a).

Outside of pollination itself, pollinators directly and indirectly provide other ecological services. Pollinators help aerate soil through the creation of nesting tunnels and they transport nutrients from flowers to their nests, where the adults and young input nitrogen through their waste into local soils (Michener 2000). Pollinators help to secure genetic diversity of endangered plants (Kearns *et al.* 1998). Conservation advocates often tout the importance of chemical extracts to cure diseases that are found in various plants around the globe. As agents of genetic exchange, pollinators increase the likelihood that certain wild plant species will be able to reproduce a next generation. Therefore, they argue, pollinators and their habitats should be protected in order to protect the plants that they pollinate, just in case their chemical constituency has pharmacological value in the future (Costello & Ward 2006). Additionally, native bee habitats, in particular, can provide ecosystem services of water filtration, regulation of hydrology and microclimates, sediment trapping, and forage and shelter for other agriculturally beneficial organisms (Klein *et al.* 2002; Kreyer *et al.* 2004).

Despite obvious synergies between bees and farms, bee conservation in agriculture faces obstacles. Around the world, pollinator populations are declining due to land use change by way of habitat fragmentation, alteration and conversion; pesticides and herbicides; infestations of parasites; and introductions of nonnatives (Buchmann & Nabhan 1997; Kearns *et al.* 1998; NRC 2007). Habitat fragmentation prevents pollinators from sustaining viable population sizes because as they become spatially isolated, subpopulations can experience genetic drift and inbreeding depression thereby increasing their susceptibility to disease (Kearns *et al.* 1998). Fragmentation can also prevent pollinators from successfully pollinating enough plants to keep pollen sources viable. Over time both the plants and pollinators decline in number (Bhattacharya *et al.* 2003; Goverde *et al.* 2002; Kearns *et al.* 1998).

On-farm agricultural practices can have direct impacts on native pollinator populations. Using marginal lands for crops reduces wild host plant populations and nesting sites on the edges of farm fields. Monocultures eliminate floral diversity thereby reducing the diversity of visiting pollinators (Kearns *et al.* 1998). Pesticides and herbicides also impact native pollinators by killing them directly or by eliminating flowering plants that provide their nourishment (Ahnstrom & Weibull 2005; Bohan *et al.* 2005; Kevan 1999; Sachs 2003). The introduction of genetically modified crops and global climate change will potentially affect species composition and, consequently, pollen availability and habitat accessibility (Bohan *et al.* 2005; Kudo *et al.* 2004).

Declines in pollinator populations cause concern for farmers (Thomson 2001; Watanabe 1994). Growers that rely on managed honey bees for their pollination services are concerned about infestations of parasitic mites from Asia, *Varroa* spp. and *Acarapsis woodi* and subsequent diseases that have devastated colonies nationwide (NRC 2007). Native pollinator decline, primarily caused by habitat alteration and chemical use, will disproportionately affect those farmers that rely solely on unmanaged insect pollinators to sustain vegetable production.

Pollinators provide myriad services to humans (Kearns *et al.* 1998; Kevan 1991) and for this reason efforts to enhance pollinator protection are gaining momentum as fears of losses in pollinator diversity surface around the globe (Cane & Tepedino 2001; NRC 2007; Tepedino *et al.* 2000). In the 1990s, scientists and land managers from around the world started piecing together data that indicated a decrease in numbers within certain pollinator species. A meeting was convened, the *International Workshop on Conservation and Sustainable Use of Pollinators in Agriculture*, in Brazil in 1998 to develop a strategy to assess the problem of decline and to develop measures to reverse it. Today multinational studies enlist scientists and resource managers to monitor pollinator populations. The networked International Pollinators Initiative, the European Pollinators

Initiative, the African Pollinators Initiative, the Brazilian Pollinators Initiative and the Oceanic Pollinator Initiative, have connected scientists and resource managers who seek knowledge about the fate of pollinators in their respective locales (API 2008; BPI 2008; EPI 2008; IPI 2008; OPI 2008).

North America also is involved in pollinator monitoring and protection through a partnership of more than 100 organizations and agencies who together form the North American Pollinator Protection Campaign (NAPPC) (NAPPC 2004). Since its inception in 1999, NAPPC has provided momentum for several national and international projects aimed at acknowledging, assessing and mitigating pollinator population declines. By way of NAPPC's request and encouragement, the National Research Council published a report, entitled *Status of Pollinators in North America*, that outlines gaps in knowledge about pollinator decline, potential implications of species loss and recommendations for rectifying the situation (NRC 2007). NAPPC's efforts also furthered the signing of Memorandums of Understanding (MOU) with federal entities within the United States government, including the United States Forest Service and the United States Fish and Wildlife Service, and NAPPC is working with additional agencies to sign MOUs in the near future. The MOUs emphasize the role of pollinators in the nation's natural and cultivated ecosystems and suggest ways of incorporating pollinator protection into agency policy and practice.

NAPPC also worked with the United States Postal Service to establish a set of postage stamps that celebrates pollinators which was released to the public in June 2007 (USPS 2007). In addition, the Secretary of Agriculture signed a proclamation naming June 24-30, 2007 as National Pollinator Week and the United States Senate passed

Resolution 580 that recognizes the importance of pollinators to United States ecosystem health and agriculture (SR580 2007). Additionally, several non-governmental organizations (NGOs), many of which are represented in NAPPC, are involved in pollinator protection efforts by formally recognizing corporations for the creation of pollinator-friendly habitats on private land and providing information on backyard habitats, among other activities. All of these actions signify a growing call for pollinator conservation.

Given the recent losses in commercial honey bee colonies due to colony collapse disorder and other causes over the last two decades and the consequences of these losses for pollination of certain crops, researchers around the United States and elsewhere are focusing efforts on studying the role of native bees as supplemental crop pollinators (Cane 2002; Kremen *et al.* 2004). Native bee conservation is important across all landscapes since their role as natural pollinators of numerous native plants is indispensable (Kearns *et al.* 1998). The contribution of the pollination services of native bees on agricultural lands is less known with the exception of a few well-studied species such as the orchard mason bee *(Osmia* spp.), the alkali bee *(Nomia melanderi)* and the bumble bee *(Bombus* spp.). The contributions of other native bee species is not well understood but could be substantial. Hundreds to thousands of bee species inhabit regions in the United States and conserving them on agricultural lands for the sake of pollination services and other ecosystem services potentially benefits thousands of farming operations.

Chapter 3: Suitability of Mid-Atlantic Sustainable Agriculture to Native Bee Conservation, Enhancement and Service

Currently, there is increased interest on the part of various stakeholders in restoring and maintaining pollinator-friendly habitats on private agricultural lands (Nabhan 2001; NAPPC 2004). In this chapter I will introduce Mid-Atlantic agriculture, briefly differentiate sustainable agriculture from conventional operations and explain my rationale for focusing on sustainable agriculture. I then detail sustainable agriculture characteristics and demonstrate the compatibility between native bee enhancement and sustainable agricultural practices. For purposes of this research, I have defined the Mid-Atlantic region using the Environmental Protection Agency's Region 3 Mid-Atlantic designation of Delaware, District of Columbia, Maryland, Pennsylvania, Virginia and West Virginia.

Given the ecosystem services that native bees and their habitats provide, as discussed in Chapter 2, agricultural lands are well positioned to benefit from native bee conservation, enhancement and service. Conservation in United States agriculture is not a new development and many conventional and sustainable farmers actively engage in conservation practices on their lands. Historically farmers were concerned about soil erosion, decreased soil fertility and limited water supplies. As a result they developed various techniques to address these issues decades ago (Nowak 1992). In recent decades, farmers have become increasingly more involved in the conservation of ecosystem services provided by wetlands, forests, waterways and wildlife habitats (USDA-NASS 2005).

Ecosystem services directly or indirectly benefit farms and adjacent landscapes. The most recent Farm Bills recognize this by providing programs that enhance conservation practices on United States farms (USDA 2008). Agricultural productivity—the economically viable harvest of food, fiber or wood products—is itself an indispensable ecosystem service. Besides food production, ecosystem services provide myriad benefits for agriculture such as the cycling and movement of nutrients, renewal of soil fertility, water retention and purification, and maintenance of biodiversity (Belaoussoff & Kevan 1998; Tilman *et al.* 2002).

Biodiversity refers to the "variability among living organisms […] and the ecological complexes of which they are a part; this includes diversity within species, between species and of [communities]" (Hawksworth 1997). Biodiversity is an ecosystem service because it offers value to humans in its ecosystem function and in its provision of food, medicine, aesthetics and intellectual stimulation.

Mid-Atlantic agriculture

More than a quarter of the land in the Mid-Atlantic region is devoted to agriculture with the latest census listing total farmland acreage at 22.6 million (USDA-NASS 2005). Given that agricultural lands comprise 28 percent of the land area in the Mid-Atlantic, it makes sense to try to preserve a share of terrestrial biodiversity on such an immense area of land (USDA 2002). In the region, fifty-five percent of agricultural land is cropped with the rest in the form of pasture, woodland or infrastructure such as barns, roads, ponds, *etc.*, most of which can provide habitats for pollinators in some form or another.

Pollinators are most important for vegetable production in the region. The Mid-Atlantic states earn US$321 million in annual revenue in sales of organically and conventionally grown vegetables (USDA-NASS 2005), many of which require insect pollinators (USDA 2002). An average farm in the Mid-Atlantic is 160 acres and the region's 140,900 farms gross $2.71 billion in revenue (USDA 2002). See Table 3.1 for individual state data.

Table 3.1. Agricultural data for Mid-Atlantic states.

	DE	MD	PA	VA	WV	Mid-Atlantic
Total Area (ac)	1,594,240	7,946,880	29,475,200	27,387,520	15,516,160	81,920,000
Total Farms (ac)	540,080	2,077,630	7,745,336	8,624,829	3,584,668	22,572,543
Total # Farms	2,300	12,100	58,200	47,500	20,800	140,900
Avg. Farm Size (ac)	230	169	132	181	173	160
# of farms <50 ac	1,250	5,830	21,964	17,109	5,672	51,825
(% of total farms)	(52%)	(48%)	(38%)	(36%)	(27%)	(37%)
Cropland Area (ac)	457,448	1,485,506	5,119,667	4,191,667	1,172,186	12,426,474
Annual Crop Revenue (US$)	150 million	450 million	1.32 billion	728 million	69 million	2.7 billion
%Revenue Vegetables	33.8%	13.4%	9.5%	11.0%	6.6%	12.0%
%Revenue Fruits/Nuts	1.7%	2.9%	8.3%	5.7%	16.4%	6.6%

(USDA-NASS 2005; USDA 2002)

The region houses at least 700 sustainable agriculture operations within its borders, about half of which are certified organic, and the average size of these farms is 37.3 acres (USDA 2002). Sustainable agriculture describes operations that employ environmental stewardship, practices that maintain perpetual agricultural productivity, and community engagement (NAL 2008). In addition to individual farms using sustainable farming practices, state agencies within the region also recognize the need to protect ecosystem services on agricultural lands and have developed programs for farm preservation or conservation practices. For example in Maryland, numerous tracts of farmland totaling more than 275,000 acres are preserved in agricultural easements through the Rural Legacy Program and local land trusts (FIC 2005). Through the Conservation Reserve and Wetland Reserve Programs, more than 375,416 acres in the Mid-Atlantic states are taken out of agricultural production, with some of these set-asides providing potential pollinator habitats (FAS 2005; USDA 2002).

Focus on sustainable agriculture

Differing in philosophy from conventional agriculture, sustainable agriculture minimizes use of chemicals and fossil fuels in cultivation practices, grows a diverse range of crops within a small area, and relies on direct marketing through farm stands, farmers markets and Community Supported Agriculture (CSA) contracts to bring products to the consumer. In contrast, conventional farming often incorporates chemical pesticides, herbicides and fertilizers along with fossil fuel driven machinery in their cultivation practices, maintains large fields of monoculture and relies heavily on processors and distributors to get their products to the consumer. Due to the fact that they comprise the majority of agricultural acreage, their sheer volume makes conventional farms important areas for pollinator conservation efforts and my focus on sustainable agriculture should not be seen as precluding or diminishing the need for research on native bees in conventional systems.

Conventional agriculture accounts for the vast majority of farming operations in the United States, but nevertheless sustainable farm enterprises are on the rise (CFI 2004; Lang 2005; Oberholtzer 2004; RVEC 2008; USDA 2002). Community Supported Agriculture (CSA) has experienced substantial growth in the last five years and in the Mid-Atlantic alone there are currently at least 166 CSA operations comprising 15 percent of the nation's total CSAs (RVEC 2008). Sustainable agriculture operations usually are characterized by growing a diverse set of products that are sold often via direct marketing efforts (Worden 2004). Sustainable farming practices maintain viable land for agricultural productivity as opposed to altering agroecosystems to such an extent that external inputs are required to improve or revitalize land. Sustainable farming includes several practices that aim to enhance the agroecosystem so it can be sustained for many generations.

Sustainable agriculture comes in many forms and is implemented in varying degrees. Some farmers use sustainable practices in all facets of the farming operation while others pick and choose from a vast list of practices and do not necessarily give up certain conventional practices in favor of sustainable ones (Gilbert *et al.* 2003). Farmers choose the practices that make most sense for their operation and that fit into their personal farming philosophy. Frequently, sustainable agriculture practices are found on farms where quality of the product is emphasized more than quantity produced (Gilbert *et al.* 2003).

Farmers that choose to use sustainable practices often are aware of their ecological footprint and understand that scaling up could negate benefits to the environment achieved by operating in a sustainable manner. Because of limitations in labor and machinery due to cost, many sustainable farmers cannot scale up because weeding, watering and harvesting already require substantial amounts of time. For some farmers, a philosophy that guides their desire to reduce use of fossil fuels keeps their production limited due to smaller sized mechanized machines (Gilbert *et al.* 2003). For these reasons, most sustainable agriculture enterprises are small in scale.

In terms of cultivation, many farmers practicing sustainable agriculture employ an array of techniques to enhance the quality of their farms and yields. Farmers will limit the use of chemical fertilizers, relying instead on green manure or livestock manure to return nitrogen and phosphorus to their soils (Gilbert *et al.* 2003). Sustainable farmers will also avoid using broad spectrum pesticides and instead select specific chemicals and target application (Gilbert *et al.* 2003). In the same vein, in sustainable agriculture there is a concerted effort to reduce the use of chemical herbicides for ridding fields of weeds and instead growers use tilling, cover crops and hand picking among other chemical-free techniques to reduce the impacts of weedy competitors (Gilbert *et al.* 2003).

Farmers rely on minimal tillage in order to protect certain biotic and abiotic properties of their soil, such as nutrient exchange, nematode populations and beneficial insect habitats (Gilbert *et al.* 2003). Farmers often rotate their crops in order to augment nutrient cycling and disrupt pest life cycles (Gilbert *et al.* 2003). Biodiverse crops, as opposed to monocultures, maintain a stronger buffer against heavy pest and disease attacks (Rathcke & Jules 1993; Sieving 2006; Westerkamp & Gottsberger 2000).

Suitability of sustainable agriculture for native bees

For smaller operations, especially sustainable growers with diverse cropping systems and products, pollinators are thought to be vastly important. New niche markets are emerging and expanding as more consumers demand organic, value-added, ethnic and specialty products (CFI 2004). Farmers that produce vegetables, fruits, herbs and cut flowers for the fresh market, as opposed to processing, are on the rise in the Mid-Atlantic as evidenced by the growing number of farmers markets in the area (Oberholtzer & Grow 2003). Native bees and their pollination services are likely to become more important as the Mid Atlantic's agricultural portfolio changes over time and vegetable production becomes more diverse. Certain characteristics of sustainable agriculture make these types of operations well suited to native bee conservation and utilization.

Although the land area of sustainable operations in the aggregate is small compared to that of conventional farms, their role as refugia for native bee populations is important (Belfrage *et al.* 2005; Holzschuh *et al.* 2007). Nearly 50 percent of the United States is in cropland, pasture or range (Vesterby & Krupa 1997), and protected areas are limited in size and spatial arrangement, so agricultural lands provide important sources of habitats for numerous species. In most areas, agricultural lands are not contiguous so it is important to provide bee habitats on as many parcels as possible to provide a mosaic of suitable habitats within a landscape (Kremen *et al.* 2004; Tewksbury *et al.* 2002). Farms are an important refuge for organisms that have lost habitats due to nearby development

(Knight 1999) and they house numerous species of wild mammals, birds, insects and plants in buffers on the margins of crop fields along with providing corridors for migratory species (Daily *et al.* 2003; Dix *et al.* 1997; Firbank *et al.* 2003; Horner-Devine *et al.* 2003; Maestas *et al.* 2003; Nabhan 2001; Pywell *et al.* 2004; Tewksbury *et al.* 2002; Van Buskirk & Willi 2004).

Sustainable growers often have an understanding of the importance of biodiversity on their farms (Jackson & Jackson 2002). Biodiversity in particular contributes to sustainability and productivity by providing pollination services and biological control of agricultural pests. By reducing the reliance on chemical and mechanical inputs, and by maintaining wild habitats on farm edges, farmers can enhance native bee populations on their farms. By providing foraging resources in the form of perennial flowers and allowing nesting sites to remain undisturbed by reducing tillage depth, farmers increase the probability that native bees and other pollinators will find their way to crop fields and return from year to year to help pollinate plants (Shuler *et al.* 2005).

Farmers are encouraged to provide floral resources throughout the growing season so that when crops are not in bloom, bees will continue to forage locally. Farmers can intentionally plant beneficial pollinator habitats on their farms, maintain a vegetative buffer of perennials planted in land margins around their fields, and/or rotate crops frequently enough such that at least one crop is flowering at any one time. By simply providing a diversity of flowering crops with differential phenologies, the farmer provides more foraging opportunities for pollinators (Carvell *et al.* 2007; Harvey *et al.* 2005; Lagerlof *et al.* 1992). When vegetables are not in bloom, floral plantings and/or buffers that contain perennials serve as good nectar and pollen sources for native bees. Besides vegetable crops, many farms grow native and ornamental flowers for the cut flower market and by choosing the appropriate companion plantings, these flowers can help attract bees to their vegetable crops.

Nesting habitat is also an important requirement for maintaining native bee populations on farms. Instruction manuals offer suggested areas around the farm that could potentially house bees including bare ground, sloped well-drained soils, ditch banks, snags and fallen logs (Vaughan *et al.* 2004). In the Mid-Atlantic region, there is very little research documenting where nest sites are found on agricultural lands.

To date the importance of native bees has been insufficiently quantified. The interface of a potential decline in honey bee pollination services and the increase in vegetables grown for new niche markets creates a need for better understanding the role of native bees as crop pollinators. The pollen requirements of most fruits and vegetables have been well documented. In other words, the number of pollen grains required to produce a marketable fruit is known. What is not well understood are the pollination efficiencies, *i.e.*, the per visit pollen contribution, of most species of native bees. Until these efficiencies are better quantified, it will be difficult to assess the economic contribution of bees other than honey bees. If growers are offered information about the economic benefits of maintaining populations of native bees via habitat manipulations on their farms, they are more likely to work to sustain bee populations.

Chapter 4: An Interdisciplinary Approach to Valuing Native Bees

If the recent trend in honey bee decline continues, alternative bee populations will become increasingly more valuable; therefore, it is important to investigate the opportunities and challenges associated with promoting native unmanaged bees for use in agriculture. The suitability of agricultural lands, especially sustainably managed land, to native bee conservation is immense because of the mutualist relationships between bees and floral resources on farms, both cultivated and wild (Belfrage *et al.* 2005; Winfree *et al.* 2007). Farmers benefit from pollination services and bees receive nectar and/or pollen rewards for serving growers. Using the Mid-Atlantic region as a case study, this research aims to develop detailed recommendations about the most feasible conservation approaches for native bees in sustainable agriculture.

If pollinator conservation is to occur on agricultural lands, as advocates envisage, a well-informed strategy must be developed to ensure success. The recently published National Research Council (NRC) report, *Status of Pollinators in North America*, provides a good foundation for that strategy by recognizing the need to understand the status and contributions of pollinators in agroecosystems and by acknowledging obstacles to pollinator conservation due to current gaps in knowledge about pollinators and their ecological, economic and cultural services to humans (NRC 2007). For conservation efforts to be successful, it is imperative that we understand the ecological, economic and cultural factors that generate our value of native bees, given that we do not conserve things that we do not value.

This chapter describes the approach I used to evaluate the ecological, economic and cultural factors that contribute to native bee value. In this chapter I define my use of the term value and explain how assessing value is challenging in cases where knowledge gaps are numerous, as they are in native bee research. I review the concept of ecosystem services and introduce ecosystem service valuation as a tool that has been adopted by conservation advocates for promoting native pollinators. In this discussion I emphasize the need for an interdisciplinary approach to capture multiple facets of native bee value. Finally, I overview the subsequent chapters that address the value of biodiversity and pollination services of native bees and their conservation in Mid-Atlantic sustainable agriculture.

Value

Value, a human constructed attribute, is the relative worth or utility of something. Value can include, but is not limited to, economic criteria for determining worth. The field of environmental ethics offers meticulously formulated positions on how nature is valued, two principal ones being biocentric value and anthropocentric value (Rolston 1988). Although I acknowledge the possibility of biocentric value, for purposes of this document value is defined anthropocentrically in that it is only attributed to something through the eyes and minds of humans. Assigning value to something signifies its worth or utility to humans. For example, something could play an important role in a system and therefore have significance, e.g. a mosquito population as part of a food web, but is only valued if we deem its role in the food web as somehow worthy or useful to us. If we decide that its trophic role enables the web to function and provide biodiversity, food, shelter among other valuable goods and services, then we can assign value to the mosquito population. At times, we do not discover the value of a particular member of the biotic community until it is lost.

In practice, we conserve and protect things that we value and it is our shared values that motivate groups to conserve (Kempton *et al.* 1995). We may value the item for its ability to provide goods and services for trade, such as fertile soil or veins of coal. We may value something due to its historical heritage, such as an ancient monument or rite of passage. We may value an item because it generates curiosity in our minds, as the moon does. Whether consciously or subconsciously, we each rank the items we value in order of relative worth to us. Those items with greater value (spiritual, economic, historical, *etc.*) are ranked higher when it comes time to designate priorities for conservation and protection of those items. By this logic, items whose value is made explicit have a better chance of being placed high in our ranking of priorities.

Valuing ecosystem services

An emerging tool for use in ranking conservation priorities is that of ecosystem service values. In both the popular press and scientific literature, pollination is often listed as an essential ecosystem service. Ecosystem goods and services are benefits that humans obtain from ecosystems (Daily 1997). Although the term has grown in popularity since the 1990s, the idea of describing attributes of nature that serve human welfare is not a new concept and has been around at least as long as Aristotle described the bounties of his surrounding lands (Mayhew 1999). The Millennium Ecosystem Assessment, a document with a mission of accounting and assessing the status of today's ecosystems on a global scale, delineates four types of ecosystem services: provisioning services (food, water), regulatory services (flood control, disease control), cultural services (spiritual, recreational, cultural benefits) and supporting services (nutrient cycling) (MEA 2005). More recently, scientists and resource managers have incorporated the term into conservation endeavors to support species recovery, habitat protection and ecosystem function restoration (Kremen & Ostfeld 2005; NCP 2007; Palmer *et al.* 2004).

The value of an ecosystem service can be assessed in several ways, economic and otherwise. In economic terms, value can be assigned based on the price of provisional good or service if it is traded on the market. Market value can be direct or indirect. A direct value is assessed by the purchase of the item itself, for example, the cost of a bushel of corn. An indirect value might be the price paid to visit an agritourism farm that has set up a corn maze for recreation. Goods and services that are not traded on the market can also hold economic value.

The value of wetlands for their flood control services may be assessed by the cost of damage to local housing in the absence of the wetland (Costanza *et al.* 1997). Even though the wetland itself is not traded on the market, it is possible to attribute a dollar value to that particular ecosystem service. In recent years a host of ecosystem valuation methods have been used to assess ecosystem goods and services, two of which are contingent valuation and the travel-cost method. These methods help in assigning value to particular non-traded goods and services from nature. Contingent valuation asks people what they would be willing to pay to protect particular goods or services and travel-cost methods calculate how much time and money people spend travelling to visit places that provide ecosystem services.

There are several benefits that cannot be easily assigned a monetary value, if at all. For example, cultural services may not have a direct market value despite their importance to humans (MEA 2005). The feeling one attributes to climbing a mountain and standing atop its summit or the sense of awe when standing at the base of a 100 meter waterfall are services provided by natural ecosystems; however, it is much more difficult to attribute a monetary value to these benefits. These spiritual values, the absence of a dollar value notwithstanding, contribute to an ecosystem's worth (Daily 1997).

At times, we only discover the value of an ecosystem service once we start to witness threats to that ecosystem service. In recent decades agriculture has been implicated as one of ecosystem services' greatest threats (Robertson & Swinton 2005; Vitousek *et al.* 1997). Over-fertilization of crops in the Mississippi watershed directly contributes to the problem of the hypoxic Dead Zone in the Gulf of Mexico (Pelley 1999), thereby hampering the Gulf's capacity to assimilate waste and provide healthy seafood. Dwindling flows in the Colorado River are attributable in large part to water diversion for irrigation of arid agroecosystems and negatively impact biodiversity and recreational opportunities (Postel 1997). Draining of lands for agricultural use in the Everglades region of Florida dramatically alters hydrologic processes resulting in lowered water purification capabilities (Chimney & Goforth 2001). Topsoil and nutrients washed away from agricultural fields during storm events in the Chesapeake Bay watershed smother submerged aquatic vegetation. This contributes to algal blooms, subsequently endangering nursery grounds for fish and shellfish thereby affecting the region's seafood industry (Kemp *et al.* 2004).

Ironically, agriculture in the aggregate contributes to a reduction in ecosystem services even though individual farmers consider themselves good stewards of the land (Paolisso & Maloney 2000). After all, their livelihoods are directly tied to the land, they feed the world and have a vested interest in protecting their land so that it can provide bounty into the future. Yet 60 years after Aldo Leopold published his essay, *Land Ethic*, in *A Sand County Almanac*, scores of farmers in the United States still struggle to merge ecosystem services protection and agricultural productivity without sacrificing one for the other (Leopold 1949; Tilman *et al.* 2002).

Merging conservation with agriculture is often challenging. Market forces, development pressures, institutional histories and past agricultural and environmental policies place the individual farmer in a complex balancing act of maintaining a rural livelihood in the present while trying to sustain the farm's agricultural productivity into the future by protecting the farm's other ecosystem services (Claassen 2001). At any given time, the farmer must choose among many factors that influence management of the farm. Even so, recent research suggests that farmers embrace a form of environmentalism (Paolisso & Maloney 2000), indicating the possibility for practices that protect other ecosystem services in addition to agricultural productivity to be adopted under the right cultural, economic and institutional settings.

Conservation priorities on agricultural lands have shifted over time due to changes in how we rank what we value. Where government-sponsored conservation programs once emphasized soil retention, programs now emphasize wetlands construction and wildlife habitats (Nowak 1992; USDA 2008). It is not a matter of soil losing its worth as an important feature of productive agriculture—soil retains its value—

it is its relative value compared to other features that we also value that has changed through time because we value ecosystem services differently than we did in the past.

The concept of ecosystem services provides a tool to capture the value of a particular service that humans receive from nature (Daily 1997). Today more and more conservation organizations are using valuation of ecosystem services in their prioritization of protection efforts around the world (NCP 2007). Although there is merit in assigning monetary value to ecosystem services as part of a larger conservation effort, it is important to consider other means of valuing nature outside of economics because there are many natural services that cannot be assigned a monetary value. In addition, some services are considered invaluable because without them humans cannot survive (Ehrenfeld 1988). It has been argued that valuation of ecosystem services should not solely be based upon human utility and that intrinsic value should be considered in conservation efforts (McCauley 2006).

Interdisciplinary approach

Whatever value system one chooses to use in assigning worth to pollination services, it must be explicitly specified and described in order to rank priorities among alternative values. My research aims to identify factors that are used to develop ecological, economic and cultural value associated with biodiversity and pollination services in sustainable agriculture in order to bolster conservation efforts. Interdisciplinary in nature, my dissertation research incorporates methods from the fields of ecology, environmental science, economics and anthropology.

The need for holistic research is reinforced by the notion that farmers themselves think in interdisciplinary terms. Outside of agronomy, farmers consider economics and future investments, family, heritage and legacy in their decision-making (Nowak 1992). Several researchers call for interdisciplinary approaches to environmental problem-solving (Banks 2004; Palmer *et al.* 2005) yet few studies address ecological, economic and cultural questions simultaneously in agricultural settings. Palmer *et al.* (2005) suggest that without large-scale projects that cross disciplinary boundaries, efforts to solve complex environmental problems will remain feeble.

From the standpoint of the farmer or any other stakeholder, bees are likely valued for their role in maintaining biodiversity, their provision of pollination services, and the cultural assets they symbolize such as fertility, diligence and community. Values attributed to biodiversity, pollination services and cultural assets are each composed of ecological, economic and cultural features that contribute to those values. Researchers operating within a traditional academic framework that disaggregates ecology, economics and culture cannot possibly capture the range of factors that contributes to native bee value. For this reason, the combination of knowledge from several disciplines takes on an emergent characteristic that becomes greater than the knowledge from each discipline. Pollinator scientists alone cannot protect bees on farms. Policymakers cannot design conservation strategies in a vacuum. Economists cannot assign monetary value of bees without information about pollination efficiencies. Farmers cannot implement pollinator-friendly management practices without access to resources, both informational and financial.

I am not arguing that researchers evacuate their posts in compartmentalized disciplines—we need to continue to train experts in specific fields. In addition, there is a niche for interdisciplinary research that can enable identification of opportunities and challenges that might remain undetected if viewed from within a single discipline. In developing my dissertation topic, I could not adequately address native bee conservation in such a complex web of institutional, political and economic nuances as has agriculture, without supplementing ecological research with methods from other fields. Conservation of native bees in agriculture cannot take place in the absence of requisite cultural, institutional and socioeconomic entryways, even if scientists understood all there is to know about native bee ecology and pollination biology.

An interdisciplinary approach leads to better conservation strategies because it acknowledges that there exists a range of how bees are valued and that values often are prioritized differently among various groups. To form the basis of a successful effort to promote native bee pollination services in agriculture, it is important to understand what types of bees are found on farms, which vegetables they benefit, and how farmers and scientists frame their views about pollinators in agriculture in order to assess pollinator-friendly management practices and potential barriers to their implementation. Because I needed tools from outside of ecology to answer some of the questions, I borrowed methods from environmental science, ecological economics and anthropology.

In the next few paragraphs, I delineate the structure of the subsequent chapters. I divided the remainder of the dissertation into four chapters—the role of native bees in maintaining biodiversity in Mid-Atlantic sustainable agriculture, native bee pollination services, the cultural influences on promoting native bee conservation in the region and an evaluation of conservation opportunities and challenges—with the understanding that overlap exists among the implementation of methods among chapters. Here I outline the objectives of the research and provide a brief overview of the methods employed in the subsequent chapters.

Role of native bees in maintaining biodiversity within Mid-Atlantic sustainable agriculture. In Chapter 5, I address biodiversity by discussing bee diversity, habitat use and floral resource preference in Mid-Atlantic sustainable agriculture. The findings in this chapter address critical gaps in knowledge that can guide the development of future pollinator recovery efforts on sustainable agriculture farms in the Mid-Atlantic region. To study native bee diversity and habitat preference, I censused sustainable agriculture farms in the Mid-Atlantic by trapping and identifying bees to species. To investigate habitat use of native bees, I constructed study plots at University of Virginia's Blandy Experimental Farm and observed floral visitation and constancy within mixed vegetable and flower plots. At this site, I also set up nest traps to try to determine where ground nesting bees preferred to construct nests.

Native bee pollination services. In Chapter 6, I examine potential pollination services of native bees for Mid-Atlantic agriculture. Currently, we are unable to assign adequately economic value to the pollination services provided by native bees because most native bee-crop synergies are not explicitly demonstrated in the literature. Research in this chapter describes the information needed to quantify the link between the ecosystem services of pollination and agricultural productivity of a subset of Mid-Atlantic vegetable crops. If a positive link can be established, more research and recovery efforts would be justifiable to ensure that native bee populations continue to contribute a valuable ecosystem service. This chapter assesses the need for new research designed to provide updated information about crop pollination requirements with a focus on native bees as a potentially integral pollination service provider. To help me catalogue the range of information required to assign economic worth to native bee pollination services, I set up experiments using a subset of vegetables to help understand the complexities involved in ascertaining native bee contributions to crop pollination. In this chapter I also reviewed the importance of native bees to other vegetables grown in the Mid-Atlantic and the opportunities and challenges for getting pollination needs met.

Cultural influences on promoting native bee conservation. In Chapter 7, I present research on the cultural dimensions of bees and the influence of culture on native bee conservation. Its purpose is to investigate the cultural factors that impact sustainable agriculture farmers' and scientists' perceptions of pollinators and the ecosystem services of biodiversity provision and pollination in order to inform strategies to promote native bee conservation. To explore cultural knowledge about native bee conservation in agriculture, I developed an online survey from information gathered previously during participant observation and informal interviews. The responses of pollinator scientists and managers were compared to those of Mid-Atlantic sustainable agriculture operators to test for differences that may enhance or hinder conservation outreach.

Evaluation of opportunities and challenges to native bee conservation in Mid-Atlantic sustainable agriculture. Finally in Chapter 8, I integrate my findings from Chapters 5–7 about the ecological, economic and cultural factors that contribute to native bee value. In this chapter, I critically evaluate opportunities and challenges to pollinator conservation in Mid-Atlantic sustainable agriculture by examining the findings from previous chapters of factors that influence likelihood of implementation of pollinator-friendly practices. The chapter provides recommendations that federal, state and/or local agencies can use to target efforts in particular areas where agricultural productivity and pollinator recovery efforts make the most ecological, cultural and economic sense. The chapter also discusses advantages and limitations of an interdisciplinary approach and provides recommendations for future research.

Chapter 5: Role of Native Bees in Maintaining Biodiversity within Mid-Atlantic Sustainable Agriculture

Biodiversity is the variability among living organisms and the ecological complexes of which they are a part (Hawksworth 1997). Biodiversity is an ecosystem service that offers value to humans in its ecosystem function and in its provision of food, medicine, aesthetics and intellectual stimulation (Daily 1997). In agriculture, biodiversity provides pollinators of important crops, biological agents for control of agricultural pests, and organisms that cycle nutrients and maintain soil health, among other services. In order to attribute value to native bees, I first needed to understand their role in maintaining biodiversity in sustainable agriculture. This chapter describes some of the ecological factors that contribute to the value of native bees in maintaining biodiversity. Later, Chapter 7 describes how Mid-Atlantic sustainable agriculture operators and pollinator scientists and managers rate the importance of biodiversity in agriculture and what they convey about who should be responsible for ensuring its protection.

The recently published National Research Council report, *Status of Pollinators in North America*, lists several recommendations for enhancing native bee populations. These include creating pollinator habitats, determining suites of key floral resources for use in restoration protocols, monitoring influence of restoration activities on population and community dynamics of pollinators, defining land management practices that encourage pollinator populations, and conserving existing natural habitats in human-dominated landscapes (NRC 2007). This research contributes to the report's call to action by researching native bee presence and practices that encourage native bee populations on sustainable agriculture farms.

By definition, biodiversity includes native bees and the ecosystems in which they fill a niche. To discover their role in maintaining biodiversity in sustainable agriculture, I investigated native bee diversity, habitat use, and floral resource and nesting preferences. My three main objectives were

1) to census native bee populations on sustainable agriculture farms in the Mid-Atlantic region to gain understanding about the diversity of bees available to farmers for pollination,
2) to determine what habitats in and around fields support native bee populations, and
3) to investigate floral and nesting preferences of native bees.

By augmenting my knowledge about the interactions of native bees and their habitats through observations and manipulative experiments, I could better understand the role native bees play in maintaining biodiversity on sustainable agriculture farms.

Hypotheses. In exploring how native bees contribute to biodiversity in sustainable agriculture, I tested several hypotheses. Below I list six hypotheses and the associated rationale behind my choice to test them. The first hypothesis is that native bee diversity differs among sustainable agriculture farms because each farm has a unique set of habitat types and presumably certain bee species are found only in certain habitat types. If I find that sustainable agriculture farms support a variety of native bee species, I reinforce previous research that advocates maintaining diverse habitats at the local scale of farms and within landscapes. In most areas, agricultural lands are not contiguous so it is important to provide bee habitats on as many parcels as possible to provide a mosaic of suitable habitats within a landscape (Kremen *et al.* 2004; Tewksbury *et al.* 2002). In order to gain the maximum benefit from native bees, the farmer must support and maintain a diverse suite of bee species throughout the growing season since adult bee emergence varies through time and space (Kremen *et al.* 2004).

The second hypothesis is that within mixed vegetable fields there would be a greater proportion of ground-nesting bees as opposed to cavity/stem nesting bees than among other habitat types because more bare soil was available for nest sites. There are numerous opportunities for promotion of native bees and their habitats on farms, especially in places that are not used for production such as fencerows, windbreaks, roadsides, ditches, field margins, powerline strips and tractor turnarounds (Croxton *et al.* 2002; Russell *et al.* 2005). Promoting native bees on agricultural land is relatively inexpensive and straightforward as compared to major structural changes that other conservation practices require (Vaughan *et al.* 2004).

The third hypothesis is that certain floral species are more attractive to bees and the fourth is that certain species of native bees will preferentially visit certain species of flowering plants. A diversity of bees is best supported by a diversity in flowering plants since blooms also vary temporally and spatially (Fussell & Corbet 1992; Potts *et al.* 2003). Instruction manuals that describe techniques for maintaining native bee populations invariably call for the provision of nesting sites and floral resources throughout the growing season (Delaplane & Mayer 2000; Shepherd *et al.* 2003; Vaughan *et al.* 2004). If there is an abundance of nectar and pollen sources in a given area, competition between plants for insect pollinators increases (Brown *et al.* 2002;

Fenster *et al.* 2004; Fontaine *et al.* 2006). It is important to select the appropriate companion flowers because the farmer would not want to draw the bees away from the crop to the alternate blooms if they are flowering simultaneously. The concern for the farmer would be that if non-crop species were blooming nearby or within the cropfield, the bees may preferentially choose non-crop foraging resources depending on the attractiveness of the resource and spend less time pollinating target crops.

The fifth hypothesis is that individual bees will visit conspecific flowers within a foraging trip. Floral constancy, the fidelity of a bee to forage within a species of plant vs. foraging among many equally rewarding plant species, has been documented in bees (Baum *et al.* 2004; Ne'eman *et al.* 1999; Walther-Hellwig & Frankl 2000). Constancy works well for the farmer if the bee has selected the crop plant as its foraging resource. For some bees, constancy is greater when collecting pollen rather than nectar due to the difficulties of melding pollen of different sizes, shapes and consistencies into a pollen load to carry back to the nest or hive. Floral constancy has implications for the farmer who provides equally rewarding floral resources during crop bloom since some individual bees may stay on the competing plant for longer periods. It is important to know the constancy and preference rates of bees to different flowering species within a planted field.

The final hypothesis is that bees nest within field soils adjacent to crop plants that they visit for nectar and pollen. Body size in native bees is often positively correlated with foraging distance (Gathmann & Tscharntke 2002; Greenleaf 2005). Smaller sized bees are expected to nest in closer proximity to floral resources than larger bees. I predicted that native bees would construct nests within test plots that contained floral resources since the plots contained well-drained soils and were not tilled prior to the growing season, allowing bees to establish ground nests. Findings from the research provide information for farmers about placement of beneficial pollinator habitats on the farm.

<u>*Native bee census*</u>

Site Selection and Methods. Study sites included ten farms from across the state of Maryland, one in Pennsylvania, and one in West Virginia (see Figure 5.1). These farms were selected because they grew vegetables, including cucurbits—crops that require pollinators—and because they used minimal, if any, pesticides. This management technique improves the comparability between sites and low pesticide use is preferred for this type of study since the application of these chemicals could impact the results of the study (Kremen *et al.* 2002; Wickramasinghe *et al.* 2004; Wickramasinghe *et al.* 2003). All sites were on privately owned and managed lands. Eleven of the farms are Community Supported Agriculture (CSA) farms with customers receiving produce, herbs and cut flowers throughout the growing season either onsite or at farmers markets. At the time of the study, six of the sites had managed honey bee hives (*Apis mellifera*) either onsite or on neighboring lands.

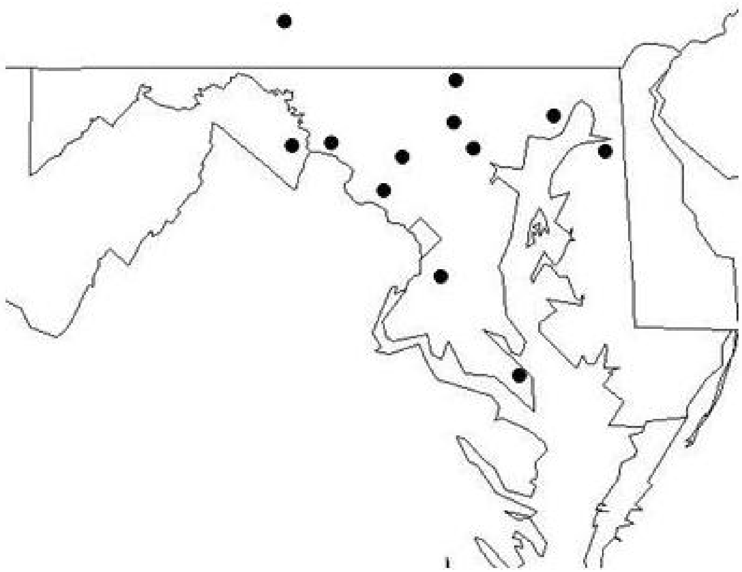

Figure 5.1. Map of bee census sites in Maryland (10), Pennsylvania (1) and West Virginia (1).

During the summer of 2005, I surveyed the 12 farm sites in each of June, July and August for bees and other insects using 50m transects of painted fluorescent pan traps in order to assess the diversity of bees in different habitats on a small set of sustainable agriculture farms. The bowl trapping method was based on the Bee Inventory Plot Protocol designed by several researchers who met at the USDA Bee Biology and Systematics Laboratory in Logan Utah in 2002 (http://online/sfsu.edu/~beeplot/). Using 10 bowl traps per transect at 5m intervals, I sampled bees along five transects at each farm. Since body length and foraging distance are positively related (Gathmann & Tscharntke 2002; Greenleaf 2005) and because small solitary bees may not travel farther than 150 m away from their nest sites to forage (Gathmann & Tscharntke 2002), choosing a smaller area for sampling ensures that both near and far foragers are likely to be sampled. I placed the transects in up to four different habitats on any one farm including vegetable crops and cut flowers, shrubs, forest edges, meadows, grass lawns and wetlands; all farms had fewer than five habitat types so some transects were set in duplicate habitats. Along each transect, I collected data on habitat type, nearby habitat types and temperature. During each collection period, I visited the study sites on the first day to set the traps and returned 24h later to collect insects from the traps. Insects, except for Lepidoptera, were placed in 70% ethanol. Bees were cleaned, dried, pinned and labeled with location information to prepare them for identification. I identified bee species using Mitchell's guides (Mitchell 1960, 1962) and the DiscoverLife online keys to bees of the Eastern United States (DiscoverLife 2008) except for *Lasioglossum* spp. that were identified by S. Droege at the United State Geological Survey Patuxent Wildlife Research Center in Beltsville, Maryland.

Analysis. Native bee diversity was measured using abundance and richness of females (EstimateS software v8.0) and compared using a general linear model (GLM) with post hoc Tukey mean comparison tests in SAS (v9.1) to look for differences in richness and abundance among habitats, among farms, and across sampling periods. Male bees were not included in the diversity measures because female bees provide the vast majority of pollination services due to the special hairs on their bodies for transporting pollen that male bees lack. I used an analysis of covariance (ANCOVA) to determine if bee diversity was a function of habitat type, month and habitat x month interaction. A significant interaction term would have indicated that bee diversity responded to habitat type differently in at least some months. A non-significant interaction term from the ANCOVA would allow samples taken each month to be used as replicates in a regression analysis to examine the relationship between bee diversity and habitat type.

Results. Among the 12 study sites I collected 3189 individual bees representing five families, 26 genera and 81 species. Two specimens were determined to be state records, *i.e.*, the first occurrence of that species in the state. *Hylaeus hylalinatus* is an introduced species from northwest New York into Ontario and was found on a farm in southern Pennsylvania in Jefferson County. *Cemolobus ipomoeae* is a morning glory specialist native to the region found on a farm in Maryland near Harper's Ferry, WV about 60 miles northwest of Washington, DC in Frederick county. Among all sites, females comprised 90.2 percent (2877) of all bees collected and represented five families, 23 genera and 74 species (Table 5.1) and measures reported below refer only to females unless otherwise indicated. The species accumulation curve including the entire sampling effort through time did not reach an asymptote (Figure 5.2).

Mean abundance across sites of female bees was greatest in July 2005 in all habitats (crop, forest edge, shrub edge, meadow, lawn, wetland) indicating an overall greater abundance in bee populations in mid-summer (Figure 5.3). Mean abundance across farm sites in July (22.32 bees per transect) was greater than in June (9.95 bees per transect) and August (16.54 bees per transect) but not significantly ($F_{2,33}$=2.83, p=0.073).

Overall species richness (number of species present) was greatest in the month of July with 55 species represented across all farm sites. The proportion of common species (≥10 individuals) to uncommon species (<10 individuals) across all sites and months varied among habitats. In crops, uncommon species comprised 59.6 percent of species whereas in all other habitats, uncommon species represented more than 75 percent of species richness (forest edge 80%, lawn 80%, shrub edge 78%, meadow 88%, wetland 94%).

Across all months and farm sites mean species richness was 14.8 species. Across all sites and habitats, mean species richness was significantly greater ($F_{2,33}$=8.60, p=0.001) in July (18.83 species) than in June (11.17 species) or August (14.50 species). Richness calculated using genera was significantly lower in crop habitats in July (2.28 genera) than in June (2.88 genera, t=15.21, df=36, p<0.0001) or August (2.62 genera, t=8.62, df=36, p=0.031). There was a significant interaction between habitat type and month for genus richness therefore only crop, forest edge, shrub edge and lawn were analyzed since monthly samples could not be used as replicates and meadow and wetland had too few replicates for comparison. The presence of shrub habitat did not influence genus richness among farms. There was no significant difference detected in genus richness when I compared farms with one or two habitat types with farms with three or four habitat types.

Among bees sampled in crop habitats, including habitats on farms with managed hives, more than 96 percent were non-*Apis* (i.e., non-honey bee). Among all habitats, sweat bees (Family Halictidae) were most abundant comprising more than 80.6 percent of all bees collected (2571 total halictids, 2421 female halictids). Within crop habitats, female halictids accounted for 87.8 percent of all female bees. There were significantly more halictids in crop habitats as compared to all other habitats combined during the months of July and August 2005. Even though halictids dominate throughout the growing season, a closer look at the species level reveals that different species of halictids dominate at different times. For example, female *Agapostemon virescens*, a bee I collected in large numbers (n=439), dominated crop and forest habitats in June while female *Halictus ligatus* (n=132) dominated in July.

Ground-nesting bees accounted for 92.5 percent of bees collected in crop habitats across all farms and months as compared to forest (69.0%), grass (80.4%) and shrub (88.7%). Table 5.2 ranks species abundances of ground-nesting and cavity/stem nesting species among all sites and months. Crop habitats had the lowest proportion of richness indicating that crops attract large numbers of common species as opposed to other habitats that attract more species but with smaller counts of individuals.

In a post-hoc comparison of farms that housed managed honey bee hives and ones that did not, I tested species richness and abundance. All farms were successful in supplying their customers with pollinated vegetables so I assumed that farms lacking honey bee hives were being served by native bees because I observed and collected very few honey bees, if any, at most farms. I predicted that native bee diversity would not be impacted by the presence or absence of managed hives. In comparing farms with managed honey bee hives to those without, I found no significant difference in species richness nor abundance between groups.

Table 5.1 Numbers of female bees per family and species across all farms, all dates.

Family	Species	# ♀s
Andrenidae		**32**
	Andrena commoda	1
	Andrena cressonii	2
	Andrena nasonii	2
	Andrena perplexa	1
	Calliopsis andreniformis	26
Apidae		**402**
	Apis mellifera	15
	Bombus fervidus	36
	Bombus griseocollis	1
	Bombus impatiens	71
	Bombus vagans	4
	Cemolobus ipomoeae	1
	Ceratina calcarata	9
	Ceratina dupla	53
	Ceratina strenua	114
	Eucera dubitata	1
	Eucera hamata	1
	Holcopasites calliopsidis	3
	Melissodes bimaculata	32
	Melissodes comptoides	5
	Melissodes desponsa	2
	Melissodes trinodis	2
	Melissodes unknown	1
	Peponapis pruinosa	46
	Ptilothrix bombiformis	1
	Svastra compta	1
	Triepeolus mitchelli	1
	Triepeolus simplex	1
	Triepeolus remigatus	1
Colletidae		**12**
	Hylaeus affinis/modestus	11
	Hylaeus hyalinatus	1
Megachilidae		**10**
	Anthidium manicatum	1
	Anthidium oblongatum	4
	Chelostoma rapunculi	1
	Megachile campanulae	1
	Megachile rotundata	1
	Osmia bucephala	1
	Osmia pumila	1
Halictidae		**2421**
	Agapostemon melliventris	1
	Agapostemon sericeus	6
	Agapostemon splendens	5
	Agapostemon texanus	6
	Agapostemon virescens	440
	Augochlora pura	30
	Augochlorella aurata	281
	Halictus confusus	53
	Halictus ligatus	132
	Halictus ligatus/poeyi	1
	Halictus rubicundus	1
	Lasioglossum admirandum	366
	Lasioglossum bruneri	89
	Lasioglossum coreopsis	12
	Lasioglossum coriaceum	17
	Lasioglossum cressonii	10
	Lasioglossum illinoense	29
	Lasioglossum imitatum	31
	Lasioglossum leucozonium	3
	Lasioglossum lineatulum	1
	Lasioglossum lustrans	1
	Lasioglossum nelumbonis	2
	Lasioglossum nymphaearum	17
	Lasioglossum oblongum	3
	Lasioglossum obscurum	2
	Lasioglossum pectorale	5
	Lasioglossum perpunctatum	2
	Lasioglossum pilosum	197
	Lasioglossum platyparium	4
	Lasioglossum quebecense	1
	Lasioglossum rohweri	474
	Lasioglossum tegulare	70
	Lasioglossum truncatum	1
	Lasioglossum unknown	6
	Lasioglossum versans	1
	Lasioglossum versatum	106
	Lasioglossum zephyrum	15
Total ♀ Bees		**2877**

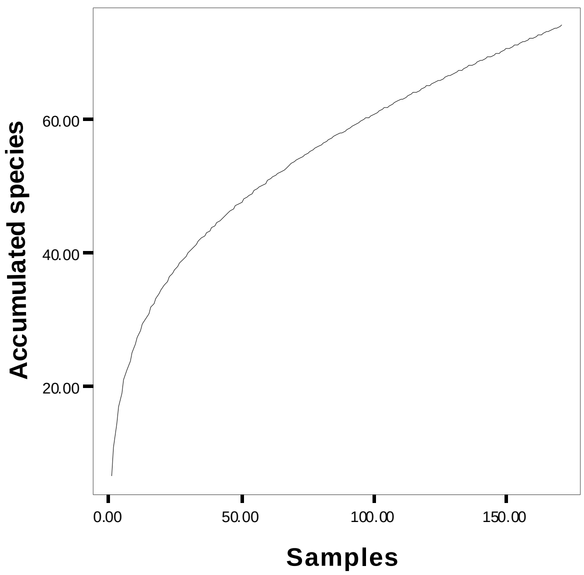

Figure 5.2. Species accumulation curve of entire sampling effort through time. Samples represent 171 pan-trapping transects among all sites in June, July and August 2005.

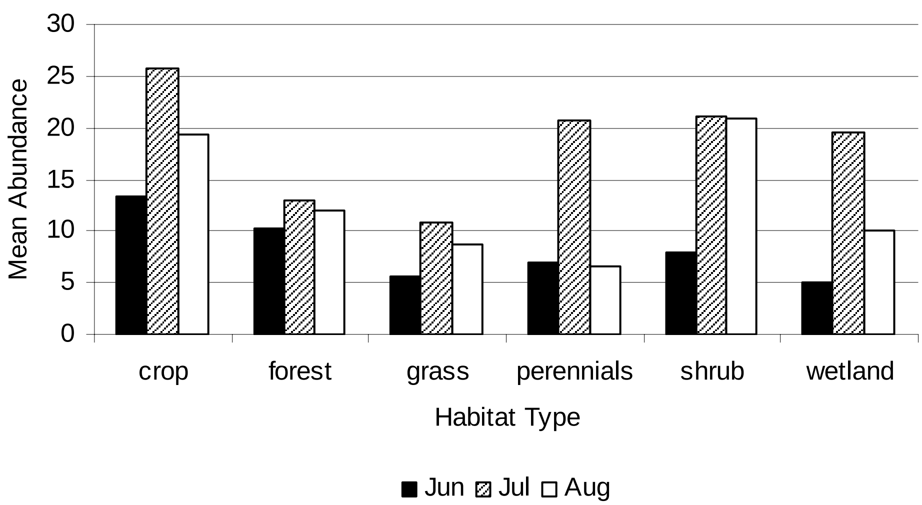

Figure 5.3. Mean abundance of female bees per transect by month and habitat type across all farm sites. With all habitats pooled, overall mean abundance across all sites is greatest in July but not significantly.

Table 5.2. Rank by abundance for species with ≥10 individuals across all sites. **Bold values** indicate ground-nesting species (n=2473), others indicate cavity/stem nesting species (n=300) (Michener 2000).

Rank	Species	Abundance
1	***Lasioglossum rohweri***	**474**
2	***Agapostemon virescens***	**440**
3	***Lasioglossum admirandum***	**366**
4	***Augochlorella aurata***	**281**
5	***Lasioglossum pilosum***	**197**
6	***Halictus ligatus***	**132**
7	*Ceratina strenua*	114
8	***Lasioglossum versatum***	**106**
9	***Lasioglossum bruneri***	**89**
10	*Bombus impatiens*	71
11	***Lasioglossum tegulare***	**70**
12	*Ceratina dupla*	53
12	***Halictus confusus***	**53**
14	***Peponapis pruinosa***	**46**
15	*Bombus fervidus*	36
16	***Melissodes bimaculata***	**32**
17	***Lasioglossum imitatum***	**31**
18	***Augochlora pura***	**30**
19	***Lasioglossum illinoense***	**29**
20	***Calliopsis andreniformis***	**26**
21	***Lasioglossum coriaceum***	**17**
21	***Lasioglossum nymphaearum***	**17**
23	*Apis mellifera*	15
23	***Lasioglossum zephyrum***	**15**
25	***Lasioglossum coreopsis***	**12**
26	*Hylaeus affinis/modestus*	11
27	***Lasioglossum cressonii***	**10**

Discussion. Diversity measures of abundance and richness are often combined into an index for ease in habitat comparisons. I chose to report abundance and richness separately because a few species and genera greatly dominated the collected samples. I predicted that certain species would only be found in certain habitat types and I found that many common species are found across all habitats but that uncommon species show up more in non-crop habitats. I assume that, to the farmer, uncommon species and singletons, those species represented by one individual, are less important for pollination of multiple crops. Species richness comparisons are informative for the conservation community and the analyses comparing genus richness among habitats are useful for agricultural producers given that closely related species frequently share similar morphologies and behaviors (Michener 2000).

In terms of pollination services, functional diversity of native bee populations presumably is more important because different bee morphologies enable differential movement within and among flower corollas. For example, bees of smaller body size may aid more in self-pollination due to their prolonged length of visit and path of movement on an individual flower whereas a larger bee aids more in cross pollination since it moves more quickly between flowers (Greenleaf & Kremen 2006b).

Even though overall and mean abundance among habitats was highest in July, genus richness was lowest indicating a dominance of certain genera during that time. Species richness was highest in July but mainly due to the variety of halictids represented in just a few genera. For the farmer, this implies that individuals of certain bee species could be present in large quantities but not continuously throughout the growing season. Bee populations fluctuate through time within and among seasons so the farmer would want to maintain a diversity of species on the property. The farmer would also want to use minimal tillage since a majority of bees are found in crop habitats and are likely nesting there. As I predicted, bees collected in crop habitats contained a majority of ground-nesting bees, indicating that they most likely nest nearby to where they forage.

The dominance of females in collected samples is explained by a combination of population characteristics as well as behavioral differences that influence trapability in the bee bowls. After mating and laying eggs in the nest, a female provisions her progeny for weeks or months depending on the species. Most bees engage in mass provisioning in which the female supplies the egg or pupa with enough food for rearing and seals that brood cell only to be reopened to remove feces (Michener 2000). Whether she has eight or hundreds of cells to provision, the female is more likely to get caught in a pan trap because she is out looking for pollen and nectar and the fluorescence of the traps imitates a floral resource. The males, on the other hand, emerge to seek a mate. They will forage for nectar on flowers but will also wait for females on leaves or near nests. In many species males die soon after mating. The likelihood of capturing males in pan traps at the rate of females is low due to their behavioral and longevity factors. It is the females that are responsible for pollination—they are the ones collecting pollen and potentially moving it to conspecific flowers. The females provide a direct service to farmers while the males indirectly contribute by ensuring a next generation of female pollinators. The farmer probably does not have to manage for gender ratios of native bees. In most cases, managing a farm parcel to attract female bees will suffice to maintain populations of that species since male resource needs overlap with those of the females.

Although sampling resulted in collecting 23 genera of females, 11 of these genera are represented only by a few individuals (n=1–6). It is not clear whether these abundances are a function of bee presence or trapping efficiency (timing of sampling, attractiveness of pan traps). For the farmer, species diversity is probably less important than functional diversity for pollination of diverse crops. This has implications for management protocols especially if it is found that particular native bees outperform others in terms of benefits to the farmer. Setting up an analogous system for a certain native bee species that encourages monospecific pollinator dominance like that of the honey bee would be ill advised.

Floral resource use and nesting

Site selection and methods. Floral constancy and visitation studies took place at the University of Virginia's Blandy Experimental Farm, Clarke County, (30°04′N, 78°04′W) in the Shenandoah Valley of northern Virginia (elev 190m) where the growing season averages 165 days and annual rainfall averages 94cm/yr. Landscape types at Blandy include grassed parkland, old fields, cow pastures, woodlots and cultivated fields of hay and alfalfa. Between May–Aug 2006, I constructed and prepared two 20m x 30m deer- and rabbit-excluded field plots in order to investigate native bee visitation to floral resources within mixed vegetable and flower fields. The plots were sited 750m apart from one another within the northwest and southeast corners of a 24.5ha (60.5ac) hayfield. Soils in the northwest plot were dominated by Poplimento silt loam while soils in the southeast plot were dominated by Nicholson-Duffield silt loams (NRCS 2008). Both soils are well-drained. To prepare plots in April 2006, I removed vegetation using a tractor-pulled disk plow followed with a rototiller. Mulch from leftover hay bales was placed on top of cultivated rows. No soil amendments, herbicides or pesticides were used in either years 2006 or 2007.

Each plot contained nine 1.25m wide rows, 22m long. Rows were separated by black landscape fabric to reduce need for weeding. I planted four cucurbit crops (watermelon, *Citrullus lanatus*; cucumber, *Cucumis sativus*; squash, *Cucurbita pepo*; cantaloupe, *Cucumis melo*) commonly found at the sustainable agriculture sites that I had surveyed in 2005. Vegetable seedlings started in the greenhouse earlier in the spring were transplanted into eight adjacent rows in mid-June 2006. Each plot contained 80 plants of each type of vegetable plant. In the same plots I planted four types of ornamental flowers: zinnia (*Zinnia elegans*), marigold (*Tagetes erecta*), sunflower (*Helianthus annuus*) and cosmos (*Cosmos bipinnatus*). The flowers, 60 plants of each of four types, were planted 15cm apart in the ninth row. Even though ornamental flowers are thought to have less nutritive resources for bees, during summer of 2005 I collected numerous native bees along transects within cut flower plots at several farms. These particular ornamental cut flowers were chosen because they are popular among growers at farmers markets. Once crop flowers and cut flowers were in the greatest numbers of simultaneous bloom in early September, I collected constancy data on two consecutive days (Sep 9–10) by following single bees (n=117) for four consecutive flower visits, recording time spent at each flower to measure floral constancy and visitation length.

During summer 2007, I investigated floral preference by native bees in a field plot of vegetables and native and cultivated flower varieties at Blandy Experimental Farm. The plot contained eight 1.25m wide rows, 22m long with landscape fabric between rows to reduce weed pressure. I selected crop and flower varieties based on estimations of phenology to ensure simultaneous bloom. These flower varieties are often found in bouquets at farmers markets or used as cover crops on sustainable agriculture farms. To emulate farmer practices, I deadheaded flowers every few days, just as growers would do in managing field plots to keep flowers blooming. Native varieties included perennial bee balm (*Monarda didyma*, n=60), perennial mountain mint (*Pycnanthemum pilosum*, n=60) and annual black-eyed Susan (*Rudbeckia hirta*, n=60). Cultivated varieties included annual sunflower (*Helianthus annuus*, n=32), annual calendula (*Calendula officinalis*, n=32), annual common buckwheat (*Fagopyrum esculentum*, n=64), annual dill (*Anethum graveolens*, n=14), annual flax (*Linum usitatissimum*, n=60), annual okra (*Abelmoschus esculentus*, n=60) and annual bell pepper (*Capsicum annuum*, n=60).

Plants were randomly placed within rows with no more than 12 plants of a kind in a set. All plants were seeded in the greenhouse in mid spring and transplanted into the plot in late spring. On 12 sunny days in between August 27–September 9, I walked randomized transects along each of eight rows, once in each direction at 15m per minute between 0930 and 1015 hours, and recorded presence of bees and wasps visiting flowers. I chose those particular morning hours based on prior trials to maximize bee diversity and simultaneous open blooms of flowering plants. I recorded bees to genus, species when possible, and noted wasps using morphological characters due to my unfamiliarity with identifying wasps on the wing.

As a mentor for two students involved with National Science Foundation's Research Experience for Undergraduates program, I oversaw two other sets of experiments that involved floral visitation studies as part of their overall investigations.

In summer of 2006, my student and I investigated the ability of two native floral species, bee balm (*Monarda* sp.) and mountain mint (*Pycnanthemum* sp.), to attract parasitoid and generalist predatory wasps that prey on the tobacco hornworm (*Manduca sexta*) using caterpillar parasitism and removal as proxy indicators of wasp presence (Keene 2006). In summer 2007, my student and I investigated the effectiveness of marigold (*Tagetes erecta*) as a pest-repellent and pollinator attractor to squash (*Cucurbita pepo*) (Warren 2007).

To investigate nesting resources I constructed open bottom pyramid live traps made from row cover fabric, clear plastic bottles and landscape pins. I tried to collect native bees that emerged from their underground nests in the field plot used in the floral visitation study. Traps covered $3m^2$ ground area and were placed just before dusk and checked during mid-morning to allow time for bees to emerge for foraging. Pilot trials on three previous dates in June, July and August demonstrated that the traps successfully collected bees if they were present but finding appropriate sampling sites proved difficult. From September 9–11 I set out 24 traps, three replicates over each of six field plant sets, bare field and surrounding mowed hayfield to investigate whether late season bees were visiting nests among different vegetation types. Traps over field plants also covered surrounding landscape fabric.

Analysis. To test floral constancy of native bees among available blooms, I used chi-square analyses. Due to high densities of all floral species, each bloom variety was considered equally likely to be visited on second and subsequent bee visits. For the floral visitation trials, for each sampling day I pooled flower blooms to obtain total and relative abundance counts for the plot and pooled total and species bee visits from all transects. I used Pearson correlations to measure the relationship between flower abundance and number of bee visitors. I ran analyses of covariance to test for the effect of date on flower abundance and bee preference and then tested differences among floral preferences among bees using GLM (SAS v9.1) with post hoc Tukey mean comparison tests.

Results. In the floral constancy experiment, bees preferred the same floral species on second, third and fourth visits (n=256) at a significant rate (χ^2=175.6, $p<0.001$) with all flowers pooled. For bees that switched to non-conspecific flowers, *Lasioglossum* spp. and *Bombus* spp. switched more often than the others but not significantly so. The few flowers that were abandoned during second or subsequent visits were proportionately abandoned at the same rate.

In the floral visitation study, across the 12 days, there was no relationship between total or relative abundance of flowers and the number of bee visitors for any flower species except for buckwheat which showed a positive relationship between total or relative abundance of flowers and number of bee visitors (r=0.619, p=0.042). Excluding buckwheat, I compared visitation among the rest of the flower species by first running an ANCOVA to test for effect of date on visitation. Date did not affect the total number of bees visiting any flower species and bees in the aggregate did not preferentially choose any flower species. Per flower relative densities were significantly correlated with date for bee balm, black eyed susan, buckwheat, flax, mountain mint and sunflower however only buckwheat showed a significant positive correlation between relative flower density and number of bee visits. In looking at the family Halictidae, the sweat bees preferentially chose black eyed susan (11.50 mean visits per day) over flax flowers (3.58 mean visits per day) across days with observed halictid visits. *Bombus* spp. and *Ceratina* spp. did not preferentially choose flowers species. Relative abundance of buckwheat flowers significantly decreased through time as did bee visits to buckwheat. When I ran analyses using the four most abundant flowers (black eyed susan, calendula, flax and sunflower) to compare per flower bee visitation, calendula had significantly more visitors per flower than flax ($F_{3,44}$=4.07,p<.01) driven mainly by halictids.

Twenty four nest traps placed within the field plot captured zero bees during the sampling period.

Discussion. The results support other similar findings of floral constancy among different bee species (Kunin & Iwasa 1996; Waser 1986; White *et al.* 2001). In the face of equally rewarding flowers of another species, individual bees choose conspecific flowers. Using Waser's (1986) distinction from preference, that bees choose flowers *because* they are more rewarding than other flowers, floral constancy describes the situation where multiple bees of a species may utilize multiple species of flowering plant during their foraging trips, indicating that one particular floral species is equally likely to be visited by that bee species, yet individual bees forage within one floral species. The results also show that no particular flower species was abandoned more than any other by those bees that did stray from conspecific flowers nor did any flower species attract bees that strayed more often. This further supports the precondition that bees were not discouraged by less rewarding flowers.

The floral visitation studies indicate that many of the flower species already grown on local farms provide good foraging resources for bees. Despite halictids preferentially choosing *Rudbeckia hirta* over *Linum usitatissimum* and *Calendula* *officinalis*, overall it appears that a diversity of floral species at any given time, although ideal, is less important than a providing a diversity of foraging resources through time.

Based on the high number of ground-nesting halictid bees I collected in crop habitats, I assumed that those bees would also be nesting within crop rows. It is often the case that ground nesting bees, even those solitary species, will nest in aggregations. Due to this clustering pattern, regular sampling may not result in finding nests. The traps that I used worked in capturing bees when placed over known nest sites so I know the lack of finding bees in the field test plots was a function of lack of nests under the traps or bad timing, not trap inefficiency. Setting up the traps was a labor intensive process limiting sampling effort. With more intensive sampling, both in time and space, the probability of discovering where nests are built would be increased. If nests were found it would be important to record soil type, moisture content, slope, aspect, pH, temperature, among other variables, so it can be determined where bees are likely to nest on farms. By quantifying nest site characteristics, scientists can better provide recommendations to farmers about maintaining potential nest sites on their property to sustain bee populations from year to year.

Conserving native bees for biodiversity

On the surface, conservation of native bees in agriculture is theoretically ideal given that the provision of bees on farms improves the likelihood that pollination services would be received on site for relatively little cost—a win-win for conservation and agricultural productivity. An important distinction in conservation approaches becomes apparent, however, when you take a closer look at the purpose of native bee conservation.

If native bee conservation is driven by biodiversity advocates who highly value species diversity, conservation can take on a very different form than those efforts that agricultural producers might employ to maintain pollinators on farm because at some level of species richness, certain bee species may become redundant in their utility to the farmer in terms of pollination services. The relationship between diversity and function is under much debate, especially in the field of restoration ecology (Cardinale *et al.* 2000).

Most conservation biologists would argue that loss of any bee species is objectionable, regardless of its redundancy in its role as a pollinator. For this reason, I argue that conservationists should stress the importance of differential bee emergence and availability throughout the growing season and among years to ensure that at any one time, different species will be present in different abundances. Chapter 8 revisits the role of that native bees and their habitats play in contributing to biodiversity value.

Chapter 6: Native Bee Pollination Services in Mid-Atlantic Sustainable Agriculture

For many farmers, the value of pollinators is predominately economic because without adequate pollination, numerous fruits and vegetables would not grow into marketable products and seeds would not be produced to plant into next year's fields. For this reason a measure of the economic worth of pollination services is needed to help mitigate the recently diagnosed decline in pollinators (NRC 2007). The economic value of an ecosystem service is an important tool in the conservation advocate's toolkit, especially when the service is essential to livelihoods and nutritional health, as is the pollination of crops. The difficulty lies in attributing economic worth to pollination services of particular pollinators because, to date, there remain important unknowns.

If the goal is to determine economic value of pollination services, several questions need to be addressed. First, we need to understand which crops require pollinators and whether the crops have specialist pollinators or can be visited by generalist pollinators to receive adequate pollination services. It is important to know if honey bees are indispensable in the particular system or if alternative pollinators can supplement or replace honey bee pollination. The economic costs associated with maintaining different pollinators vary and those costs are not well established except for managed hives of honey bees. And finally, the pollination efficiencies of alternative pollinators is an important factor in determining the economic value of all pollinators to a particular crop yet for most native bees their contributions to individual crops is not well understood.

Over the past few years, a small number of studies have estimated the economic value of pollinators by determining the loss in agricultural outputs in the absence of those pollinators (Greenleaf & Kremen 2006a; Kevan & Phillips 2001; Klein *et al.* 2003; Olschewski *et al.* 2006; Ricketts *et al.* 2004). These estimates have the potential to inflate pollinator value by assuming loss in output is due to pollinator loss alone and not also due to a lack of other essential inputs that contribute to crop yield as well—water, fertilizer, labor and the like (Hoff 1995). These general estimates require fine-tuning, notwithstanding, the goal of my research is not to calculate values for particular pollinators but rather to determine the factors necessary to develop better estimates.

The purpose of this chapter is to assess the potential of native bee pollination services for Mid-Atlantic agriculture by investigating the present state of knowledge about native bee pollination services to Mid-Atlantic crops. The chapter begins by explaining pollination services in agriculture and differentiates honey bees from alternative pollinators. Then the chapter discusses gaps in knowledge and the need for research aimed at investigating pollination by native bees. Next I describe the experiments I conducted using locally grown crops that helped me catalogue what factors are required to assign worth to pollination services. Finally, the chapter discusses Mid-Atlantic vegetable production in relation to local needs and challenges for pollination services.

Pollination services in agriculture

Historically in the United States, the European honey bee (*Apis mellifera*) has served as the dominant pollinator of agricultural crops. In 1949, the number of managed honey bee colonies reached its peak at 5.9 million, compared to estimates of 2.3 million in 2002, and less today due to colony losses in the past few years (USDA 2002). Unlike most other bee species, honey bees are social and live in hives with colonies ranging from 10,000 to more than 60,000 bees depending on time of year.

Ever since early agriculturalists learned how to manage colonies by providing artificial hive baskets several centuries ago, beekeeping has evolved into an industry that now transports honey bee hives across state and national borders to provide pollination services for fruit, nut, vegetable, forage and seed crops. In the United States, some hives move from Florida to Maine or California during a growing season while others move from California to the Dakotas. The mobility of hives has enabled U.S. agriculture to expand the land base used for certain crops because bees can be rented for short periods of time to fulfill pollination needs but, consequently, has eliminated natural habitats for local pollinators by cropping fields to the margins and removing edge habitats.

Beekeepers load their trucks up with hive boxes at night while the bees are inside, move them to a new location where pollination services are requested, let the bees work the fields or orchards for a few days during high bloom, then reload the truck at night and move to the next location. It is suspected that this system of transporting hives exposes bees to harm by encouraging disease transmissibility, stress due to movement, and exposure to various pesticides throughout the season (Oldroyd 2007).

In light of the recent disruption in many managed honey bee colonies, more research is warranted to investigate how other bee species can supplement pollination for some farms. Honey bee losses could prove devastating for some vegetable and fruit/nut producers. The economic importance of the honey bee, the most managed and recognized crop pollinator, is easier to evaluate than that of unmanaged native pollinators. In the United States alone, in excess of 150 food and fiber crops estimated at more than $20 billion in annual revenue rely on the ecosystem service provided by pollinators, primarily managed honey bees, in their production (Kevan 1991), and, consequently there is increased interest on the part of various stakeholders in restoring and maintaining pollinator-friendly habitats on private agricultural lands (Nabhan 2001; NAPPC 2004).

The cost of lost pollinator services is substantial in some markets (Kevan & Phillips 2001). Colony inventory is low because beekeepers have lost colonies due to parasites or have opted not to rent because honey prices are strong and they can profit in the honey market. If the trend in honey bee decline continues, native bee populations will become increasingly more important to farmers; therefore, it is important to investigate the benefits associated with promoting native, unmanaged bees for use in agriculture.

For purposes of this document, the term *alternative pollinators* refers to all pollinating animals besides European honey bees. There exist examples of mammal and bird pollination syndromes for agriculture, but it is insect pollination that dominates. And out of the insect orders, Hymenoptera (bees, wasps and ants) provides most pollination for vegetable crops. In terms of managing alternative pollinators, only a few bee species have been successfully utilized for intensive pollination service. Bumble bees (*Bombus* spp.) live in colonies much smaller in number than honey bees. Providing nest cavities can encourage wild populations to inhabit farmland while purchased hives can be placed inside greenhouses for use for particular crops, such as tomato and eggplant. Alkali bees (*Nomia melanderi*) are good pollinators of alfalfa and can be managed by installing nesting sites onsite. The introduced alfalfa leaf cutting bee (*Megachile rotundata*) is managed by providing artificial nesting shelters and tunnels and works well as a pollinator for clover and alfalfa. Finally, orchard mason bees (*Osmia* spp.) provide adequate pollination for orchard fruits and are managed by providing artificial nest tubes onsite. While all of these bees contribute to crop pollination, there is a wide range of other bee species that are present on farms that potentially contribute services beyond what have been previously documented.

<u>Crop pollination</u>

While previous studies have addressed honey bee pollination for many crops, there exist numerous agricultural products for which very little is known in terms of native bee pollination. Cucurbits are probably best studied given that they are dioecious with heavy, sticky pollen unable to be easily moved via wind, making insect pollination mandatory (Norden 1985; Shuler *et al.* 2005; Tepedino 1981; Winsor *et al.* 1987). Nonetheless, the pollination literature contains several examples of vegetable flowers that attract pollinators but does not quantify specifically the contributions of pollen per visit for native bees. If we knew more about the biology, ecology and cultural practices associated with these crops in relation to native bees, we could better attribute an economic value to the pollination services provided. Table 6.1 lists several factors that influence the relationship between bee and crop. For some crops, many of these factors are already known, however very few crops have each variable fully described in the literature, making economic valuation difficult.

Table 6.1. Factors required for economic valuation of native bee pollination services.

Factor	*Description*
Pollination system	Plants have self-compatible pollen or self-incompatible pollen. Plants with separate male and female flowers often require cross pollination. Ways that plants encourage cross pollination are to position their pollen so that it cannot find its way easily to the stigma and/or they dehisce pollen when the stigma is not receptive. For some plants, cross-pollination is obligatory for fruit set. For others, self pollination is possible but cross pollination also occurs.
Pollination vector	Plants receive pollen from other plants by various methods. Hydrophily is the transfer of pollen by water, anemophily by wind, zoophily by vertebrate animals and entomophily by insects.
Flower morphology	Stamen, pistil and nectary arrangement greatly influences efficiency of insect visitor as pollination agent.
Length of flower bloom	The amount of time the bloom is open will influence the availability of that pollen to insect pollinators thereby increasing pollination rates by insects.
Length of flowering season	Flowering phenology influences the rate at which insect pollinators can find blooms, learn how to manipulate flowers to obtain pollen and return to that location repeatedly thereby increasing pollination rates.
Nectar content	Plants use nectar to attract insect pollinators to a blooming flower to increase pollination rates. Theoretically plants with higher nectar content use insects for pollination.
Pollen content	Bees collect pollen for self or progeny growth and/or nectar for energy depending on their gender and life stage so it is important to know what the crop provides as foraging resources.
Honey bee efficiency	If honey bees (*Apis mellifera*) are present in an area they will visit various vegetable blooms. Their efficiency may not be adequate to produce marketable fruit, however, and the role of native bees in this case is increased. For example in tomato, bumble bees do a better job of obtaining pollen through buzz pollination which honey bees do not do. Additionally, honey bees may visit the vegetable flower but will readily move to a more attractive foraging resource and therefore their efficiency is low for some crops.
Known native pollinators	Agricultural crops may have certain known native pollinators. Knowing the relationship between native bee and honey bee visitation would help in valuing pollination services. Hundreds of native bee species inhabit the Mid-Atlantic states yet documentation on their associations with and contributions to crops is insufficient.
Form of Marketable Vegetable	Although insect pollinators can be very important for seed production of vegetables, native bees may only be important for some vegetables that are sold for consumption in fruit form. Vegetables sold as leaves or roots are reliant on native bees only for the next generation of plants but not to marketable vegetable production itself.
Habitat requirements	The floral and nesting resources required to sustain native bee population and associated installation and maintenance requirements.
Farms	The number of farms that grow the vegetable influences the importance of native bees to Mid-Atlantic vegetable production.
Acres	The acreage on which the vegetable is grown influences the importance of native bees to Mid-Atlantic vegetable production
Revenue	The amount of sales of the vegetable influences the importance of native bees to Mid-Atlantic vegetable production.

The factors are based on plant and bee biology and ecology, feasibility of management for the appropriate bee, and economic factors including the importance of certain vegetables to the economy of the Mid-Atlantic region. If factors in Table 6.1 were known for a certain crop, an estimate of the importance of native bees to the pollination of the crop could be developed that could translate into an economic value for the service. Figure 6.1 illustrates how factors in Table 6.1 inform the essential questions whose answers are required to determine economic valuation of native bee pollination services.

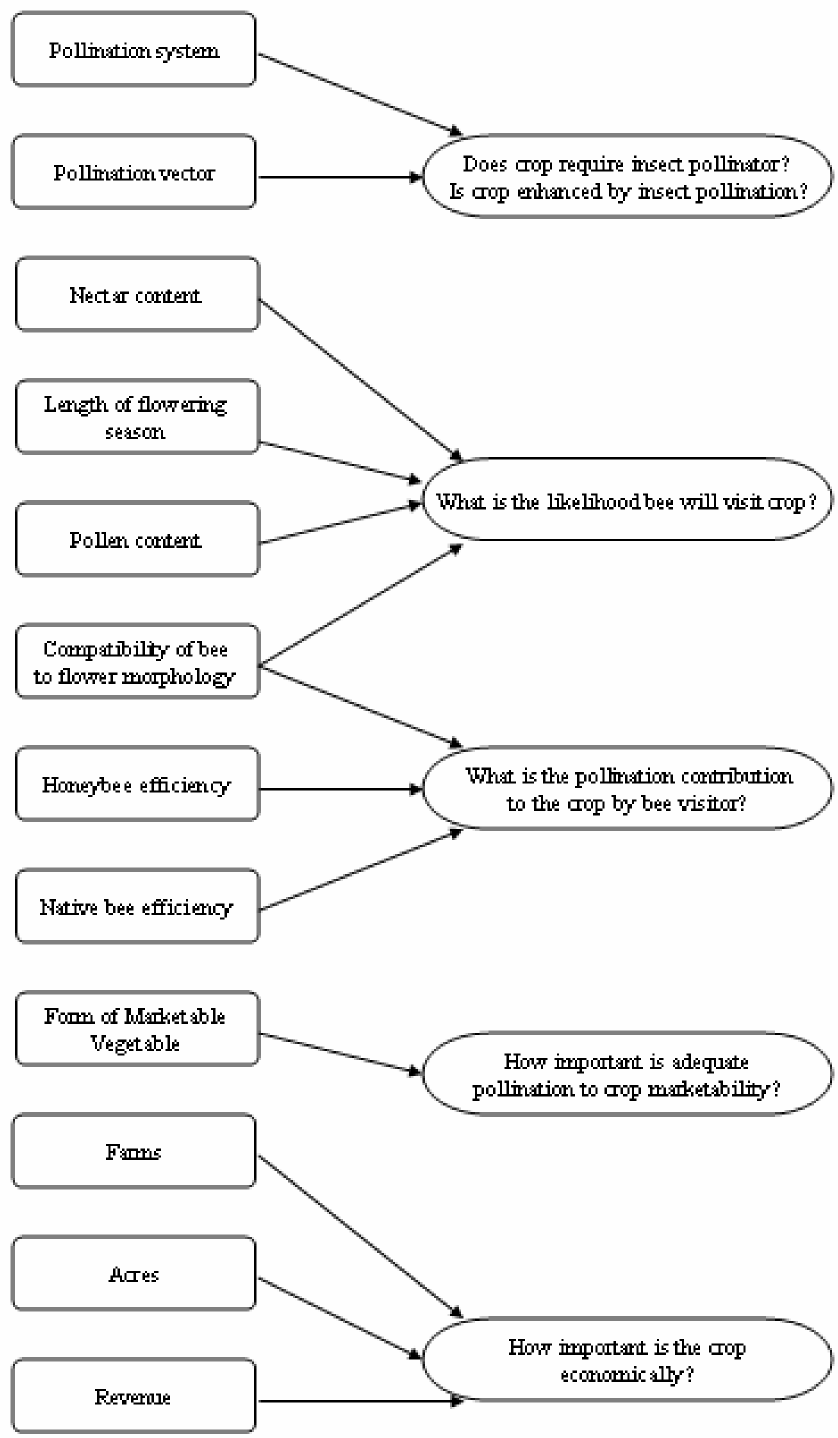

Figure 6.1. Factors that influence economic valuation. Squares enclose factors and ovals enclose the questions that need to be answered to inform economic valuation of native bee pollination services.

A series of factors contribute to the process of determining economic worth of pollinators. Nonetheless, to date empirical data do not exist to quantify many of these factors. The pollination requirements of many vegetables have been investigated in respect to the imported European honey bee, *Apis mellifera*, but less information is available about the myriad native bees, many of them solitary, and their pollen transfer capabilities and efficiencies. More research is needed on a crop by crop basis to investigate native bee contributions, especially as honey bee numbers decrease. To understand the methods involved in research on pollination services that I advocate above, I investigated two locally-grown crops to try to quantify the pollination contributions of native bees.

Pollination experiments

I selected okra (*Abelmoschus esculentus*) and bell pepper (*Capsicum annuum*) as the vegetables to study because of past research that indicated that native bees enhance quality and yield of those crops elsewhere (Al-Ghzawi *et al.* 2003; Raw 2000). A closer look at okra and pepper in the Mid-Atlantic provides information about native bees and pollination in this region. Both vegetables are self-compatible so insect pollination is not mandatory. The presence of bees, nonetheless, may enhance cross pollination thereby increasing fruit and seed set. I originally intended to study squash (*Cucurbita* sp.) as well because as a dioecious plant, it requires an insect pollinator to move pollen from the male flowers to the female flowers. Unfortunately, due to fungal wilt early in the growing season, squash was eliminated from the investigations because not enough plants survived to produce the number of fruits required for adequate sample sizes.

Okra originated from northeast Africa and is found frequently in cultivated fields in Africa, Asia, the Middle East, Europe and the United States. The annual grows from a little less than 1m to 2m tall and produces several seed pods which are harvested at an immature state for consumption. Okra flowers are 5–7cm across with five cream or light yellow petals and a style with stigma surrounded by a staminal tube with filaments. The flower is open in the morning hours and the flower wilts and falls off the following day. Anthers dehisce 15 to 20 minutes after the flower opens and some pollen comes into contact with the stigma.

Researchers in West Africa found a significantly higher rate of seed set in hand and insect pollinated plants than in bagged self-pollinated flowers and seed set ranged from highest to lowest among insect pollinated, hand self-pollinated and bagged self-pollinated flowers (Njoya *et al.* 2005). In the Middle East, researchers found significantly higher seed set in insect pollinated flowers than in bagged ones in eight genotypes of okra (Al-Ghzawi *et al.* 2003). Njoya *et al.* (2005) also discovered that halictid bees due to their smaller size probably aid more in self-pollination than the larger *Megachile* spp. that most likely aid more in cross-pollination and *Apis* spp. mainly collect nectar and do not add much pollination service.

Pepper originated in Central and South America and is found in cultivated fields globally today. Pepper is an annual plant that grows to less than 1m and produces several fruits that are harvested both immaturely and fully ripe for consumption. Pepper flowers are 1–1.5cm across with one stigma and five stamens in a bell shaped white corolla. The flower opens in the morning and lasts less than one day. Anthers dehisce a few hours after the flower opens or not at all. Pepper can self-pollinate but cross-pollination is common and entirely necessary for flowers whose anthers never release pollen. Known pollinators include honey bees, bumble bees (*Bombus* spp.) and horn-faced bees (*Osmia* spp.) (Ercan & Onus 2003; Kalev *et al.* 2002; Kristjansson & Rasmussen 1991; Roldan-Serrano & Guerra-Sanz 2006).

Based on data from the diversity research described in Chapter 5, it was evident that sweat bees, Family Halictidae, dominate in sustainable agricultural farms that I visited. To improve my understanding of their contribution to crop pollination, I set up experiments that would compare plants visited by all bees to plants visited only by smaller bees, namely halictids.

Hypotheses. I predicted that squash, okra and pepper seed counts would be enhanced by pollination from native bee visitors. In the case of squash, I predicted that I would have few successful fruits in treatments that prevented insect visitors from reaching female stigma. Also, I expected lower yields and seed counts in fruits where larger bees, namely the squash bee (*Peponapis pruinosa*), were excluded. In okra, I expected yields of flowers that small bees visited to be similar to self-pollinated yields due to the fact that small bees in West Africa were shown to move pollen within flowers while larger bees were suspected of moving pollen among flowers. For pepper, I expected the treatment that allowed large bees, namely bumble bees (*Bombus* spp.), to have the largest seed counts and yield since bumble bees are known to pollinate efficiently flowers in the *Solanaceae* family via buzz pollination.

Methods. Okra and pepper pollination studies took place at the University of Virginia's Blandy Experimental Farm, Clarke County, (30°04′N, 78°04′W) in the Shenandoah Valley of northern Virginia (elevation 190m) where the growing season averages 165 days and annual rainfall averages 94cm. In June 2007 at Blandy Experimental Farm, in a deer- and rabbit-proof fenced plot of vegetables and flowers, I transplanted 69 okra plants (var. Cajun Delight) that had been seeded in a greenhouse in May into five sets of 12–15 plants each into five randomly assigned rows. Okra plants were spaced 30cm apart. Supplemental watering via soaker hoses was added during dry periods of no rain. Each bud on a given plant was tagged and randomly assigned either to be a donor or to be one of five treatments of either control (fine-mesh bagged flower), hand self (fine-mesh bagged flower with resealable slit for hand pollination), hand cross (fine-mesh bagged flower with resealable slit for hand pollination), small insect (large-mesh [4mm hole, InterNet Inc. #ON6275] bagged flower) and ambient (no bag on flower). The large mesh would allow small flying insects to enter the flower and pilot trials indicated that sweat bees (Family Halictidae) freely entered mesh bags on buckwheat in the same plot where they were already known to forage. This particular treatment would test the contribution of small flying insects to okra pollination.

Once flowers bloomed, hand-pollination treatments were either crossed using pollen from previously assigned donor plants or self pollinated using small paintbrushes. During this time I took plant height measurements. For all treatments, once the flower fell off the plant, bags were removed and fruits allowed to develop until at least 8cm long, length at which most growers harvest okra for market. Once harvested, I measured length and volume using water displacement for each okra pod and counted expanded and unexpanded seeds for each fruit.

In June 2007, into the same deer- and rabbit-proof fenced plot of vegetables and flowers, I transplanted 65 pepper plants (var. Ace) that had been seeded in a greenhouse in May in five sets of 12–14 plants each into five randomly assigned rows. Pepper plants were spaced 30cm apart. Supplemental watering via soaker hoses was added during dry periods of no rain. Each plant was tagged and randomly assigned either to be a donor or to be one of five treatments. In this experiment, entire plants were caged due to difficulties in bagging individual pepper flowers since they often drop off the plant if jostled. Before any plants had open blooms, I assigned treatments. Cages were constructed from tomato cages and all treatments received a cage with fine mesh tops to control for available light. Donor plants were not placed in cages. The five treatments included control (fine mesh cage), hand self (fine-mesh cage with resealable slit for hand pollination), hand cross (fine-mesh cage with resealable slit for hand pollination), small insect (large-mesh [4mm hole, InterNet Inc. #ON6275] cage) and ambient (no mesh on sides of cage). The large mesh would allow small flying insects to enter the flower and would test their contribution to pepper pollination. Crawling pollinators were able to access all plants equally and it is assumed any variation caused by this was diluted by replication.

Once flowers bloomed, hand-pollination treatments were either crossed using pollen from previously assigned donor plants or self pollinated using small paintbrushes. For all treatments, I removed cages and harvested peppers on Aug 28, 36d after installing the treatments. Plant height measurements were taken at this time. I assigned each pepper a length size category of small (2–4cm), medium (4–7cm) or large (>7cm) and counted fruits per plant and expanded and unexpanded seeds for each fruit.

Analysis. In both the okra and pepper studies, to ensure that differences were explained by the treatments, I ran an analysis of covariance (ANCOVA) to test whether plant height covaried with seed number, fruit volume or length. Treatments were compared using general linear models (PROC GLM, SAS v9.1) with post hoc Tukey mean comparison tests to test for differences in mean total seed number, mean expanded seed number and mean unexpanded seed number. For okra, I also compared mean pod length and volumes among treatments. In pepper I tested whether seed number covaried with fruit size and fruit number per plant.

Results. For okra, fruit to flower ratio for all tagged buds was 1.00. Plant height was positively correlated with expanded seed number ($r=0.537$, $p<0.0001$) meeting the homogeneity of slope assumption for the subsequent analysis of covariance. The ANCOVA results showed that when adjusted for plant height, there were no significant differences between treatments. Plant height was also positively correlated with number of unexpanded seeds per fruit ($r=0.419$, $p<0.0001$) and total number of seeds per fruit ($r=0.740$, $p<0.0001$). When adjusted for plant height, significant differences among treatments were not detected in unexpanded and total seed numbers. In addition, no significant difference was detected among treatments in fruit volumes, fruit lengths or number of days from open flower to harvestable size of 8cm (Table 6.2).

Table 6.2. Means, standard deviations and sample size of okra seed counts, volumes and heights across treatments.

Okra	Number of seeds			Pod volume (ml)			Plant height (cm)		
Treatment	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*
Ambient	74.3	10.1	41	12.5	2.7	38	53.3	11.4	41
Small Insect	72.2	11.9	41	12.8	2.5	36	52.5	12.5	41
Cross	74.2	11.9	42	12.6	2.5	38	56.2	12.0	42
Self	73.0	13.2	41	12.8	2.5	36	53.5	12.2	41
Control	74.1	13.2	42	12.3	2.6	38	53.4	13.2	42

For pepper, larger fruits contained more seeds than medium sized fruits yet within each size category, no significant differences among the five treatments were detected

(Table 6.3). I did not include small peppers in comparisons since so few of the peppers in the small size class were counted due to seed damage during drying.

Table 6.3. Means, standard deviations and sample size of pepper seed counts among three pepper sizes across treatments.

Pepper size	Small (2–4cm)			Medium (4–7cm)			Large (>7cm)		
Treatment	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*	*Mean*	*SD*	*N*
Ambient	10		1	202.3	86.5	20	301.5	118.7	12
Small Insect	42	18.4	2	176.6	98.5	8	242.4	89.2	14
Cross	83		1	171.9	80.0	8	307.6	61.5	11
Self	63.5	47.4	2	141.4	123.5	5	238.2	97.1	6
Control	111.7	58.5	3	152.5	81.1	11	212.6	70.5	5

Discussion. Although bee visitation did not appear to influence seed set in the varieties of okra or pepper I selected for my experiments, other varieties demonstrate different results. Okra and pepper have been shown in other studies to benefit from native bee visitation (Al-Ghzawi *et al.* 2003; Raw 2000). These two crops are known to self pollinate successfully so it is not surprising that differences between control and ambient treatments were not observed in my experiments. It is also difficult to gauge whether the appropriate pollinators were present in the numbers required during the short time when crop flowers were blooming. If these crops had bloomed during differing weeks in the summer, I might have detected differences between treatments due to the differential abundances of bee species over time. If I were to repeat the experiment, I would start and transplant seedlings from the greenhouse in intervals since bee emergence and foraging changes though time. Due to the fact that native pollinators positively impact crop yields in certain varieties of coffee (Ricketts *et al.* 2004), tomato (Greenleaf & Kremen 2006a) and sunflower (Greenleaf & Kremen 2006b), more research is warranted to attain a comprehensive understanding of native bee pollination contributions to multiple varieties of various crops.

Pollination services for Mid-Atlantic agriculture

The Mid-Atlantic states of Delaware, District of Columbia, Maryland, Pennsylvania, Virginia and West Virginia have more than 700 sustainable agriculture operations, many of which grow vegetables requiring insect pollination. These farms are characterized by growing a diverse set of products that are sold usually via direct marketing efforts. Niche markets, value-added, ethnic and specialty products open up opportunities for growing this diverse set of products. The interface of a potential decline in honey bee pollination services and the increase in vegetables grown for these new markets creates a need for better understanding the role of native bees as crop pollinators.

For the Mid-Atlantic states, the 2002 national agriculture census lists just over 30 vegetable crops harvested for sale (USDA 2002). Of these, five are in the family *Cucurbitaceae* and require insect pollination for the ~34,000 acres grown. Other crops not included in this discussion are grain and oilseed crops, orchard crops such as tree fruits and nuts, as well as forage, wildflower and vegetable seeds since native bee contributions likely are proportionately smaller than for vegetable crops harvested for market. In Table 6.4, the top 20 vegetables are listed from greatest to least acreage along with a recommended honey bee hive per acre estimate for adequate pollination. If the number of acres in vegetable production is multiplied by the recommended hive number, a projected number of required hives is the result. In total, if the Mid-Atlantic states wanted to supply recommended hive numbers, more than 80,000 colonies would be required. Census data from 2002 recorded the number of colonies where the largest quantity of agricultural products was produced (USDA 2002). Given that the Mid-Atlantic states recorded only 65,000 in 2002 (and presumably less today due to CCD and other colony disruptions), it appears that there are not enough colonies to supply pollination needs yet despite the lack of hives, marketable vegetables were produced. This could be explained by bees foraging in more than one set of fields so their contribution is double counted. Another likely explanation is that native wild pollinators contribute a significant amount of pollination services within farm habitats.

Table 6.4. Projected honey bee hive needs for Mid-Atlantic vegetables.

Common name	*Scientific name*	*Farms (#)*	*Acres (#)*	*Suggested hives/ac*	*Projected # hives needed*
Sweet corn	*Zea mays*	3305	41028	0	0
Beans, snap	*Phaseolus vulgaris*	1292	22461	0	0
Pumpkins	*Cucurbita spp.*	2305	12311	1.5	18466.5
Beans	*Phaseolus lunatus*	217	11396	1	11396
Tomatoes	*Solanum lycopersicum*	2626	10714	0	0
Cucumbers	*Cucumis sativus*	929	10431	2.2	22948.2
Peas, green	*Pisum sativum*	287	8671	0	0
Watermelons	*Citrullus Ianatus*	1037	5846	1.8	10522.8
Squash	*Cucurbita pepo*	1408	3018	1.5	4527
Cantaloupe	*Cucumis melo*	1170	2642	1.8	4755.6
Spinach	*Spinacia oleracea*	126	2473	0	0
Peppers, Bell	*Capsicum annuum*	1616	2278	0	0
Cabbage, head	*Brassica oleracea*	551	2222	2	4444
Peppers, Chile	*Capsicum annuum*	626	851	0	0
Collards	*Brassica oleracea*	147	675	2	1350
Asparagus	*Asparagus officinalis*	397	547	1.7	929.9
Kale	*Brassica oleracea*	149	389	2	778
Beets	*Beta vulgaris*	273	342	0	0
Broccoli	*Brassica oleracea*	313	337	2	674
Lettuce	*Lactuca sativa*	232	280	0	0
Totals		19006	138912		80792

If a ranking system for vegetables in the order of their needs for native bees could be developed, growers could adjust their management practices based on the types and abundances of native bees desired. As stated above, the pollination efficiencies of many bees still need investigation. Until more research is conducted on the pollination requirements of crops in relation to native bees, in the meantime we need some way to rank the potential importance of native bees to Mid-Atlantic agriculture in order to prioritize conservation efforts and design incentives for management practices.

I propose that research concentrate on those crops that are known to require bees and study them in similar experiments to what I designed for okra and pepper in order to look for pollination contributions from non-honey bees. Based on information gathered from sustainable agriculture farmers, as described in other dissertation chapters, I believe that demonstration projects on private lands would have the most impact for moving research and outreach forward. Involving growers in the research enables exchange of ideas onsite and allows for iterative adaptive management opportunities as growing conditions change through time.

Reliance on European honey bees may provide inadequate pollination if recent losses to colonies continue. If this scenario occurs, more emphasis on alternative pollination schemes will become necessary to retain agricultural viability for vegetable growers. Already some farmers are seeing the advantages of diversifying their crop portfolio to remain competitive. This also increases the likelihood that multiple species of bees can be supported and will preferentially choose diversified farms because of the diversity of plants grown onsite. One important change that would benefit bees and farmers would be the shift to growing wildflower seed for use in restoration projects, agricultural cost-share conservation practices, highway roadside plantings and other uses. In this scenario, farmers grow perennials for seed and sell the seed to government agencies. The call for restoring lands with native plants is often hindered by the lack of seed stock. Growing wildflower seed for profit is well suited to coupling native bee conservation with pollination services.

Given that farmers can receive a direct benefit of pollination services, the benefits and costs of conservation of native bees on agricultural lands should be quantified. The costs of implementing these conservation practices must be considered when valuing pollination services. There are certainly costs associated with providing habitats for native bees and due to cultural practices already in place, installation and maintenance expenses are site specific. For fields that abut natural areas, native bee abundances will likely be higher (Kremen *et al.* 2002) given that these adjacent areas provide nesting and foraging resources in times when crop fields do not. Costs are low at these sites because maintenance is minimal. Installing and maintaining conservation strips with perennial bee forage and nesting substrates, on the other hand, will cost the farmer more than if pollinator habitats already exist nearby. Simultaneous to understanding pollination contributions of native bees, a better understanding of the type and size of habitat required to sustain the appropriate population sizes of native bees is needed so that growers can provide adequate foraging and nesting resources in order to get the maximum benefit of pollination in return.

Chapter 7: Cultural Influences on Promoting Native Bee Conservation in Mid-Atlantic Sustainable Agriculture

In light of the recent losses in commercial honey bee colonies due to colony collapse disorder (CCD) and other causes over the last two decades and the consequence of these losses for pollination of certain crops, researchers around the United States and elsewhere are focusing efforts on studying the role of native bees as supplemental crop pollinators (Greenleaf & Kremen 2006a; Klein *et al.* 2007). Native bee conservation is important across all landscapes since their role as natural pollinators of numerous native and cultivated plants is indispensable (Kearns *et al.* 1998). Hundreds to thousands of bee species inhabit regions in the United States and conserving them on agricultural lands for the sake of pollination services potentially benefits thousands of farming operations.

To promote conservation, the recent National Research Council (NRC) report, *Status of Pollinators in North America*, recommends that pollinator advocates inform the agricultural community "about current knowledge on actions (such as creating habitat) that can be taken to manage pollinators" and conduct studies to understand the "land manager's willingness to adopt restoration practices"(NRC 2007). Sustainable agriculture farmers already hold beliefs, values and knowledge about pollinators and ecosystem services conservation. Therefore, before outreach approaches are formulated there is a need to understand what farmers already know and believe about pollinator conservation. Understanding the influence of cultural beliefs, values and knowledge on the way different groups view conservation will help scientists convey their message about the importance of pollinator conservation in a more constructive fashion and will help farmers relay information about pollination needs as growers.

An important goal of this chapter's research was to elicit values and beliefs from farmers and pollinator scientists/managers about pollinator services in order to assess barriers and opportunities for pollinator conservation. I hypothesized that sustainable agriculture producers as a group view pollinator conservation differently than pollinator scientists and managers due to differences in shared cultural beliefs within groups. The chapter discusses how backgrounds and experiences influence beliefs and values among groups and in doing so describes the general themes in which cultural factors potentially influence native bee conservation. I outline the research methods I used to elicit values and beliefs within these broad themes from sustainable agriculture producers and pollinator scientists/managers. Finally, I present the results of the study and describe how cultural factors influence native bee conservation in Mid-Atlantic sustainable agriculture.

Cultural influence on conservation

The objectives of the research are to examine the cultural beliefs, values and knowledge that influence native bee conservation in order to develop recommendations that capitalize on opportunities and manage challenges appropriately. Investigating the differences in how producers and scientists/managers frame general themes, such as agricultural preservation, pollination, biodiversity and outreach, can help guide conservation efforts so that they account for cultural differences in how groups conceptualize and prioritize factors within these themes. Information obtained also contributes to understanding perspectives about the role of biodiversity on agricultural lands and who bears the responsibility to provide and maintain habitats that support biodiversity.

The cultural analysis was iterative in that initial informal interviews informed a survey instrument distributed later in the study. Using an online questionnaire (see Appendix 2), I examined values and beliefs that affect producers' and scientists/managers' conceptualization of pollinators. Cultural factors that affect native bee conservation in sustainable agriculture were examined within the larger context of conservation in agriculture; therefore, this research also examined values and beliefs about broad concepts such as biodiversity and conservation. Results from the survey can help identify where the beliefs and values of producers and scientists diverge, thereby clarifying where native bee conservation outreach can be improved. By gathering information about cultural beliefs, values and knowledge, an investigator can better understand the interactions between cultures and whether constructive dialogue among stakeholder groups is likely (Paolisso 2006).

Members of the agricultural community and advocates of ecosystem services—assuming these are two different groups, or cultures—may view the world through different cultural filters and therefore are not necessarily conveying the same meaning even when they use similar language. An individual's worldview or cultural model influences how a particular conservation program or practice will be received and interpreted (Kempton *et al.* 1995). It is these cultural models that contribute to the disconnect between agricultural and environmental interests (Kempton *et al.* 1995; Paolisso & Chambers 2001). Cultural models represent the filters through which people see the world. Within a culture there are values, beliefs, norms and rules that help shape an individual's cultural model and these models are shared among members of that culture. Cultural models influence how new information is absorbed and interpreted by individuals and groups.

Historically, farmers expended time and energy taming the wild by clearing their land and ridding it of weeds and undesirable wildlife. Ecosystem services proponents now want to bring the often unwanted natural diversity back onto the land. To illustrate, take the example of the farmer who chooses not to participate in a practice designed to provide an ecosystem service such as installing grass buffers along streams to help purify water. The farmer claims the reason for refusal to participate is because the potential introduction of weedy species is an unappealing consequence and could negatively affect agricultural productivity. Yet in fact the underlying reason the farmer is reluctant to participate is because a high value is placed on neat, clean, tidy edges to crop fields. In this case the farmer interprets "grass buffer" as "untidy weed patch," not because "grass buffer" wasn't meticulously defined in a planting manual or program brochure but because the farmer defines an environmental aesthetic based on farm-based cultural beliefs and values (Maloney & Paolisso 2006).

If native bee conservation is to gain any ground in agriculture, it is imperative that researchers and farmers have open channels to exchange information about pollinator habitat requirements and pollination needs of the grower and that messages are not misinterpreted. Conservation management practices often spread throughout the agricultural community via outreach. Outreach, the dissemination and discussion of information and ideas with others, is important for information sharing, yet at times this conduit can be partially blocked by cultural and political barriers. In the United States, traditional agricultural outreach developed out of the missions of land-grant institutions to serve agricultural producers, consumers and the general public by providing information about agriculture-related production, marketing, finances, health and safety based on research conducted within academia. Information was often disseminated to farmers through land-grant universities and county Cooperative Extension offices. The message and messenger were often the link between the farmer and government agencies. In the first half of the century, government programs helped farmers retain their soil, maintain certain prices on commodities, and insure compensation for crop failure. During the Green Revolution after World War II, government agents helped farmers incorporate chemical fertilizers and fossil-fueled machinery into their farming practices. Two decades later they started delivering a different message when ecosystems starting showing signs of major degradation from agricultural activities, creating a sentiment of mistrust of government and academia among many farmers.

The diffusion of information through networks has been well studied in and outside of agriculture (Rogers 2003). Diffusion network theory attributes the spread of new ideas and practices to the established formal and informal connections and interactions among members of a social system. With the invention of the World Wide Web, these networks have grown beyond the local scale, especially for producers that rely on the Internet for marketing their product and therefore have frequent access to a linked computer. For scientists' research findings to reach the intended practitioner or end-user, the information must be condensed and edited into comprehensible content, packaged into attractive forms of media, and then delivered through the appropriate channels whether they be extension agents, other growers, sales representatives, libraries, websites, *etc*. Whether the information is received and used by the recipient is influenced by several factors including the perceived credibility of the source, the applicability and adaptability to the current practices of the end-user, and the economic and social costs associated with implementing the suggested practices, among others.

The NRC report on pollinators recommends outreach to the agricultural community in order to disseminate information about the importance of pollinators (NRC 2007). Sustainable agriculture farmers already hold beliefs, values and knowledge about pollinators and biodiversity conservation; therefore before outreach approaches are formulated, there is a need to understand what farmers already know and believe about pollinator conservation and how they prioritize it among other needs of the farming operation. Sustainable farmers' interests in environmental stewardship do not necessarily correlate with their ability to use ecosystem services to their greatest advantage. Furthermore, for community supported agriculture (CSA) farmers in the Northeast, although environmental stewardship is a motivating factor for running a CSA operation, it falls behind marketing, community and education on the list of priorities (Worden 2004). Therefore, it should not be automatically assumed that sustainable agriculture farmers prioritize pollinator conservation. In fact, as evidenced by the disparate number of talks about pollinating insects *vs.* other beneficial insects that prey on agricultural pests, there appears to be a bias toward pest control over pollination services at sustainable agriculture conferences.

Eliciting cultural beliefs and values

Participant Selection and Methods. The Mid-Atlantic states of Delaware, District of Columbia, Maryland, Pennsylvania, Virginia and West Virginia house more than 700 sustainable agriculture operations. These farms are characterized by small acreages that grow a diverse set of products usually sold via direct marketing efforts. Niche markets, value-added, ethnic and specialty products open up opportunities for growing this diverse set of products, many of which require the pollination services of native bees. The cultural analysis study focused on two groups—sustainable agriculture producers and pollinator scientists/managers. Given that sustainable agriculture producers generally subscribe to three main principles of sustainability—environmental health, economic viability and social equity (Schaller 1993), and that pollinators provide good indicators of environmental health (Belaoussoff & Kevan 1998) and provide a direct service to the farm, I wanted to investigate the potential for native bee conservation practices to be implemented on farms in the Mid-Atlantic.

I chose sustainable agriculture farmers as the study group, assuming their views would be most similar to pollinator scientists and managers but nevertheless hypothesizing that enough differences between the two groups exist to impact outreach efforts about native bee conservation. The producers group was comprised of Mid-Atlantic vegetable growers, hay farmers, honey collectors, cut-flower growers, orchard growers, livestock growers, or any combination thereof, that practice sustainable agriculture. The pollinator scientists/managers group was made up of scientists and managers actively involved in pollinator research and conservation from across the United States.

Starting in June of 2005, in conjunction with bee census research I was conducting on sustainable agriculture farms, I engaged in participant observation (Agar 1996) at 12 sites in the Mid- Atlantic. On these farm visits, I informally interviewed resident farmers about their beliefs and values in regard to pollinators and biodiversity conservation. During this time I also attended sustainable agriculture talks and conferences around the region and informally interviewed producers about their opinions on implementing pollinator-friendly practices on their lands. Included in my interviews were questions about participants' knowledge about bees, fears of bees, hindrances to conserving bees and the burden of responsibility for conservation in agriculture. Out of the notes I had recorded after these interviews, I developed a set of survey questions that addressed pollinator conservation in agriculture. I compiled the questions into a paper survey that served as a pre-test and distributed them while staffing a pollinator exhibitor booth at the February 2007 Pennsylvania Association for Sustainable Agriculture conference. Using the suggestions and comments I received from the pre-test, I developed an online survey of 34 questions for all respondents plus an additional 17 questions available only to producers that asked about their farming characteristics.

The survey was distributed in two ways using electronic means since this is the most cost effective manner to collect survey data (Sue & Ritter 2007). In my Internet searches for sustainable operations described previously in Chapter 5, I discovered that many farms use electronic direct marketing techniques and advertise on individual websites indicating their use of the Internet. With Internet surveys, often the probability of missing data is lower and participants perceive this method as less time consuming

(Sue & Ritter 2007). Additionally, transcription errors are reduced since data is electronically stored at the time the respondent submits the survey.

In the first method I sent an initial recruitment email informing the potential participant that they would be receiving another email from a web-based survey service, SurveyMonkey.com, with a link to the online survey (see Appendix 1). To gather participant names in the Mid-Atlantic states I searched Local Harvest, a nationwide web-based directory that lists small farms, farmers markets and other local food sources as using sustainable practices. Other names were obtained from sustainable agriculture directories furnished on individual state agriculture department websites. In total, I collected 705 names of sustainable operations.

For the scientists/managers study population I collected names from a partners list posted on the North American Pollinator Protection Campaign website and supplemented the list with some names of researchers listed as authors on scientific publications on pollinators (NAPPC 2008). This list consisted of 191 names.

I was able to obtain email addresses for 474 producers and out of that amount, 58 recruitment emails bounced back due to out of date or incorrect email addresses leaving 416 potential participants that received the survey. Out of the 191 scientists/managers pool, 12 emails bounced back so thus 179 potential participants received the email. For those operations that requested paper and pencil surveys in response to the initial recruitment email, a hardcopy of the recruitment letter and survey was available.

The second method was by sending a link for the survey to three listservs—Sustainable Agriculture Network Discussion Group, Plant Conservation Alliance and Medicinal Plant Working Group. Only those responses from listserv respondents that fit the criteria of Mid-Atlantic producer or pollinator scientist/manager were included in the analyses. The survey was placed online and tested in late spring 2007 and the initial recruitment email was sent in July with a reminder following in August 2007. Results included data collected through mid-September 2007.

Questions elicited answers in several formats including single answer multiple choice, multiple answer multiple choice, fill-in for numbers or geographic locations, yes/no choice, ratings, rankings, and an open-ended feedback box at the end for questions, comments, or reactions from the respondents.

Analysis. Using SAS v9.1 and SPSS v15.0, I used descriptive statistics to determine frequencies and chi-square goodness of fit tests (Fisher's exact tests when necessary) to compare nominal data responses between producers and pollinator scientists/managers. I used Mann-Whitney U tests (Wilcoxon rank-sum tests) to compare ordinal data responses between groups. Relationships among variables were analyzed using Spearman's rho correlations.

Results. Of the 705 Mid-Atlantic producers on the original list, I received 102 completed surveys (24.5 percent of the 416 that received the recruitment email), all of which came from the recruitment emails. No hardcopy surveys were received. Although I received an additional 25 online responses from producers from the listserv requests, none of those responses were included in the analyses because they resided in places outside of the Mid-Atlantic states. Response rates from individual states are listed in Table 7.1. Of the 191 scientists/managers on the original list, I received 57 completed surveys (31.8 percent of the 179 that received the recruitment email) with an additional

32 coming from the listserv requests meeting the pollinator scientist/manager criteria for a total of 89 completed surveys.

I compared demographic and farm characteristics data between producers and scientists/managers groups (Table 7.2). Most respondents were between the ages of 30–60 and female respondents were just slightly under half (49% producers, 46% scientists/managers). Education levels ranged from high school graduate or equivalency to doctorate degree and the scientist/managers possessed significantly more advanced degrees than the producers, of whom 69 percent had at least a bachelors degree.

Of the producers, 86 percent owned farm land and 22 percent rented, indicating that some farmers do both. Producers had run their agricultural operations from 0 to 20 years with the majority (32%) working their land between 11 and 20 years. Most operations were less than 20 acres (73%) with 43 percent using only 0 to 5 acres to produce their goods. Sixty percent of the farmers tilled their land and almost 39 percent had managed hives on their property for at least part of the year. For hive owners, median cost of operating the hives was US110.00yr^{-1}$ and renters spent a median of US200.00yr^{-1}$. Thirty-six percent of the respondents who owned or rented hives believed colony collapse disorder (CCD) was affecting their honey bee colonies. Operations produced a variety of goods, and acreage on any given farm was dedicated to the following (percent of operations that produced the product): fresh market vegetables (86%), pasture (66%), cut flowers (65%), hay (53%), orchard fruits or nuts (52%), feed grains (24%), seed (19%) and food grains (17%). Management styles ranged from organic to conventional and operations were self-selected as certified organic (24%), pesticide free (60%), herbicide free (56%), fungicide free (55%) and conventional (22%).

Most operations marked farmers markets as *very important* for product sales (50%) followed by community supported agriculture (CSA) subscriptions (31%) and farm stands (27%).

Beliefs about agriculture varied between producers and pollinator scientists/managers (Table 7.3). The two groups of respondents ranked reasons for preserving agricultural landscapes similarly except when it came to biodiversity protection and keeping agricultural locally viable. More producers ranked agricultural viability as *most important* as compared to other rankings and proportionately more scientists/managers ranked protecting biodiversity as the *most important* reason than did producers.

Producers were asked how important particular factors were to their operations and scientists/managers were asked which factors they thought were most important for producers in their area. Significant differences were detected in how the two groups ranked three of the four factors. Adequate water, adequate soil amendment and adequate pest/disease control were ranked differently between the two groups. Noteworthy was the fact that adequate pest/disease control was ranked less important by farmers than scientists and managers. Pollination was ranked similarly between the two groups.

When asked questions about pollinators and diversity, producers and scientists/managers agreed on many variables but there were some differences in knowledge and beliefs (Tables 7.4, 7.5 and 7.6). A larger percentage of producers thought there were fewer bee species in their county than scientists/managers. The majority in both groups underestimated the number of bee species most likely present (101–1,000). Both groups selected a preferred term for non-honey bees similarly. *Native bees* was most preferred followed by *pollinating bees* and both groups ranked all of the six choices in the same preferred order. Among managed honey bees, feral honey bees and native bees, a larger percentage of producers thought that native bees do most of the pollinating on farms than did scientists/managers.

Interestingly, producers and scientists/managers believed hummingbirds and bats play a larger role in agriculture than they probably do. Also, more scientists believe that flies and beetles are beneficial insects than do producers. Very few respondents were afraid of bees (<9% of each group) even though about 80 percent within each group of respondents have been stung by a bee. The groups were equivalent in the percentages of having bee allergies in the family. The two groups differed in their beliefs about all bees having the ability to sting. A larger percentage of producers thought that all bees can sting. Even though the answer to the question they were given in the survey is false, 10 percent of pollinator scientists/managers believed it to be true.

All consequences of pollinator loss were ranked differently between the two groups (Table 7.6). Both groups ranked the loss of beekeeping as the least important consequence yet their distributions of rankings were dissimilar. Most respondents in both groups ranked loss of biodiversity as the most important consequence. The second most important for producers was adequate pollination of crops whereas scientists/managers divided second and third rankings almost equally between loss of crop pollination and loss of native plants that require pollinators. The importance of research needs was ranked in similar orders of importance between the two groups, however the distributions made the rankings of economic benefit of pollinators, pollinator censuses and GM crops significantly different.

Beliefs and values about biodiversity differed in some respects but not others between the two groups (Table 7.6). Proportionately fewer producers believed that taxpayers should pay to protect biodiversity on agricultural lands or receive a green payment for doing so. When asked if producers would be willing to implement pollinator-friendly practices on their properties in the absence of a payment to offset their costs, only 71 percent of scientists/managers believed they would as opposed to 93 percent of producers who stated that they would be willing to do so.

The results of the outreach section of the survey show differences between producers and scientists/managers in how information is sought and distributed (Table 7.7). Groups were asked about who was responsible for distributing information about pollinators. More scientists/managers ranked nongovernmental organizations (NGOs)/non-profit organizations in the top three rankings than did producers. Additionally, producers believed that commercial suppliers/trade representatives have a greater responsibility for disseminating pollinator information than scientists/managers did. Producers and scientists/managers also ranked differently groups that need information the most. Public land managers were not thought to need the information by producers. More scientists/managers ranked government agencies as less in need. The places the two groups look for pollinator information differs as well. More producers look to other growers. Trade magazines are more important for producers, as are commercial suppliers. Libraries and conferences are ranked high among scientists/managers in comparison to producers. Both groups heavily rely on the Internet as a source for information. Finally, 49 percent of pollinator scientists/managers interact with farmers as part of their job responsibilities at least monthly.

I also received numerous comments from potential participants and respondents. Fourteen people contacted me directly by replying to my recruitment email. An additional 71 comments were posted in the feedback box at the end of the survey. These comments ranged from appreciation and encouragement for the research, to comments about question wording, to opinions about the current status of bees, pollination and agriculture in general, to suggestions of contacts and helpful resources, among others (Appendix 3).

Table 7.1. Respondent tallies and response rates from Mid-Atlantic states resulting from recruitment email.

	DC	*DE*	*MD*	*PA*	*VA*	*WV*	*Mid-Atlantic*
Population	2	11	160	304	194	34	705
Email Sent	0	9	26	177	134	25	474
Email Received	2	7	101	163	119	24	416
Responded	0	4	35	43	32	8	122
Completed	0	4	32	33	27	6	102
Response Rate	0.00	0.57	0.32	0.20	0.23	0.25	0.25

Table 7.2. Demographic information of all respondents and farm characteristics of Mid-Atlantic producers**.** Gender compared using Chi-square; age and education compared between groups using Mann-Whitney U tests.

Characteristic	*Mid-Atlantic Producers (N=102)*	*Scientists Managers (N=89)*	*Significance*
Age range			z=-1.075, ns
under 21y (%)	1.0	0.0	
21-30y (%)	3.9	11.2	
31-40y (%)	16.7	21.3	
41-50y (%)	26.5	19.1	
51-60y (%)	40.2	37.1	
61-70 (%)	9.8	9.0	
over 71y (%)	2.0	2.2	
Highest education level			z=-6.104p<0.001
High school graduate or equivalency (%)	3.9	1.1	
Some college (%)	23.5	3.4	
Associates degree (%)	3.9	0.0	
Bachelors degree (%)	33.3	16.9	
Masters degree (%)	23.5	44.9	
Doctoral degree (%)	11.8	33.7	
Gender			χ^2=0.166, ns
female (%)	49.0	46.1	
Own farm land (%)	86.0		
Rent farm land (%)	22.0		
Years running agricultural operation			
0 to 5 years (%)	28.0		
6 to 10 years (%)	24.0		
11 to 20 years (%)	32.0		
More than 20 years (%)	16.0		
Acres used to produce goods (last 3 yr)			
0 to 5 acres (%)	43.0		
6 to 10 acres (%)	14.0		
11 to 20 acres (%)	16.0		
21 to 50 acres (%)	5.0		
51 to 100 acres (%)	4.0		
More than 101 acres (%)	18.0		
Till cropland (%)	60.0		
Have managed hives (%)	38.6		
Median annual cost to own hives ($)	110.00		
Median annual cost to rent hives ($)	200.00		
Believe CCD is affecting hives (%)	35.9		

Table 7.3. Beliefs of Mid-Atlantic producers and pollinator scientists/managers about agriculture. Rankings compared using Mann-Whitney U tests.

Belief (1=most important… 5=least important)	*Mid-Atlantic Producers*					*Pollinator Sci/Mgr*					*Sig, p-value*
	1st [%]	*2nd* [%]	*3rd* [%]	*4th* [%]	5th [%]	*1st* [%]	*2nd* [%]	*3rd* [%]	*4th* [%]	*5th* [%]	
Reason for preserving agricultural landscapes											
To maintain a rural way of life	9.8	17.6	16.7	30.4	25.5	9.0	7.9	18.0	33.7	31.5	ns
To keep agricultural locally viable	63.7	25.5	7.8	2.9	0.0	44.9	25.8	21.3	5.6	2.2	0.002
To decelerate land development	7.8	24.5	31.4	14.7	21.6	13.5	33.7	23.6	12.4	16.9	ns
To maintain sense of community	0.0	6.9	19.6	39.2	34.3	1.1	3.4	24.7	33.7	37.1	ns
To protect biodiversity	18.6	25.5	24.5	12.7	18.6	24.6	27.2	18.8	13.6	15.7	0.032
Importance to agricultural operation											
Adequate water	69.0	20.0	9.0	2.0		54.5	15.9	17.0	12.5		0.008
Adequate soil amendment	17.0	38.0	23.0	22.0		5.7	30.7	36.4	27.3		0.014
Adequate pollination	7.0	28.0	42.0	23.0		10.2	23.9	22.7	43.2		ns
Adequate pest/disease control	7.0	14.0	26.0	53.0		29.5	29.5	23.9	17.0		<0.001

Table 7.4. Beliefs of Mid-Atlantic producers and pollinator scientists/managers about beneficial insects and pollinators.

Belief/Value	*M-A Producers*	*Pollinator Sci/Mgr*
Insects considered beneficial to agriculture		
Adult ants (%)	0.62	0.56
Adult bees (%)	1.00	1.00
Adult beetles (%)	0.54	0.72
Adult butterflies (%)	0.78	0.76
Adult flies (%)	0.43	0.70
Adult moths (%)	0.47	0.57
Adult spiders (%)	0.86	0.75
Pollinators essential to producing marketable goods		
Managed honey bees (%)	0.52	0.84
Feral honey bees (%)	0.68	0.70
Wild bees (%)	0.85	0.97
Butterflies (%)	0.66	0.53
Beetles (%)	0.37	0.53
Flies (%)	0.35	0.52
Ants (%)	0.33	0.33
Hummingbirds (%)	0.40	0.40
Bats (%)	0.39	0.52

Table 7.5. Beliefs/values of Mid-Atlantic producers and pollinator scientists/managers about bees. Compared using Mann-Whitney U tests.

Belief/Value	*M-A Producers*			*Pollinator Sci/Mgr*			*Sig. p-value*
Estimate of # bee species in county							<0.001*
0 to 10 species (%)		24.5			7.9		
11 to 100 species (%)		58.8			47.2		
101 to 1,000 species (%)		16.7			37.0		
1,001 to 10,000 species (%)		0.0			7.9		
Preferred term for non-honey bees							ns
Native bees (%)		42.2			53.9		
Non-Apis bees (%)		4.9			3.4		
Pollen bees (%)		2.9			2.3		
Pollinating bees (%)		39.2			29.2		
Solitary bees (%)		2.9			2.2		
Wild bees (%)		7.9			9.0		
Bees that pollinate most on farms							0.014
Managed honey bees (%)		29.6			50.0		
Feral honey bees (%)		14.3			8.0		
Wild bees (%)		56.1			42.0		
	Yes	*No*	*DK*	*Yes*	*No*	*DK*	
Afraid of bees (%)	3.9	96.1		9.0	91.0		ns
Believe all bees can sting (%)	27.5	72.5		10.1	89.9		0.003
Believe killer bees in county[1] (%)	6.9	93.1		13.5	86.5		0.019
Fear killer bees (%)	41.2	58.8		33.7	66.3		ns
Stung by a bee (%)	79.4	12.8	7.8	79.8	14.6	5.6	ns
Anyone in family allergic to bees (%)	23.5	66.7	9.8	24.7	66.3	9.0	ns

[1]only includes sci/mgr in Mid-Atlantic

Table 7.6. Beliefs/values of Mid-Atlantic producers and pollinator scientists/managers about pollinators and biodiversity. Compared using Mann-Whitney U tests.

Belief/Value	*M-A Producers*				*Pollinator Sci/Mgr*				*Sig. p-value*
(1=most important…4=least important)	*1*	*2*	*3*	*4*	*1*	*2*	*3*	*4*	
Consequences of pollinator loss									
Loss in overall biodiversity (%)	45.1	23.5	12.8	18.6	66.3	16.9	12.4	4.5	0.001
Loss in adequate pollination of crops (%)	36.3	33.3	22.6	7.8	14.6	30.3	43.8	11.2	<0.001
Loss of native plants (%)	15.7	48.3	30.3	5.6	10.8	31.4	38.2	19.6	0.001
Loss of beekeeping as an industry (%)	7.8	11.8	26.5	53.9	3.4	4.5	13.5	78.7	<0.001
*(**V**ery important, **S**omewhat, **N**ot, **D**on't know)*	*V*	*S*	*N*	*D*	*V*	*S*	*N*	*D*	
Importance of research needs									
Colony collapse disorder (%)	77.5	16.7	2.9	2.9	64.0	30.3	3.4	2.2	ns
Economic benefit of pollinators (%)	53.9	38.2	5.9	2.0	68.5	25.8	3.4	2.2	0.046
Agricultural pest control (%)	52.0	44.1	3.9	0.0	47.2	43.8	4.5	4.5	ns
Wild pollinator population censuses (%)	53.9	43.1	1.0	2.0	69.7	27.0	0.0	3.4	0.035
Agricultural weed control (%)	35.3	53.9	10.8	0.0	28.1	58.4	9.0	4.5	ns
Disease transmission in pollinators (%)	49.0	44.1	3.9	2.9	52.8	40.4	1.1	5.6	ns
Effect of GM crops on beneficials (%)	73.5	17.6	5.9	2.9	53.9	33.7	10.1	2.2	0.009
	Yes		*No*		*Yes*		*No*		
Farms important for biodiversity (%)	97.1		2.9		88.8		11.2		0.024
Ag producers responsible for biodiversity (%)	93.1		6.9		93.3		6.7		ns
Taxpayers pay producers for biodiversity (%)	62.8		37.2		79.8		20.2		0.010
Concern if no wild bees on farms (%)	94.1		5.9		98.9		1.1		ns
Want to increase # of wild bees on farm (%)	98.0		2.0		98.9		1.1		ns
Receive green payment for biodiversity (%)	67.3		32.7		87.5		12.5		0.001
Want cost-share for pollinator practices (%)	91.1		8.9		97.7		2.3		ns
Implement practices w/o cost-share (%)	93.1		6.9		70.5		29.5		<0.001

Table 7.7. Beliefs/values of Mid-Atlantic producers and pollinator scientists/managers about pollinator outreach. Compared using Mann-Whitney U tests.

Belief/Value (1=most important… 4=least important)	*Mid-Atlantic Producers*					*Pollinator Sci/Mgr*					*Sig. p-value*
	1st [%]	*2nd [%]*	*3rd [%]*	*4th [%]*	*5th [%]*	*1st [%]*	*2nd [%]*	*3rd [%]*	*4th [%]*	*5th [%]*	
Responsible for info distribution											
Commercial suppliers/trade reps	12.7	15.7	20.6	19.6	31.4	5.6	6.7	11.2	39.3	37.1	0.010
Extension agents	49.0	27.5	10.8	9.8	2.9	50.6	25.8	15.7	5.6	2.2	ns
Individual farmers	3.9	7.8	20.6	32.4	35.3	1.1	7.9	14.6	33.7	42.7	ns
NGOs/non-profit organizations	10.8	20.6	25.5	22.5	20.6	11.2	27.0	37.1	18.0	6.7	0.026
Scientists	23.5	28.4	22.5	15.7	9.8	31.5	32.6	21.3	3.4	11.2	ns
Groups that need info most	(only top 5 of 8 rankings here)										
Agribusiness	20.6	15.7	8.8	16.7	11.8	16.9	9.0	13.5	7.9	9.0	0.036
Extension offices	12.7	30.4	14.7	15.7	9.8	12.4	19.1	13.5	20.2	7.9	ns
General public	6.9	12.7	9.8	11.8	17.6	9.0	12.4	9.0	13.5	10.1	ns
Government agencies	3.9	5.9	12.7	10.8	10.8	3.4	9.0	13.5	21.3	14.6	0.016
Individual farmers	27.5	20.6	18.6	10.8	11.8	25.8	13.5	11.2	16.9	13.5	ns
Policymakers	13.7	4.9	13.7	17.6	13.7	18.0	22.5	15.7	10.1	11.2	0.006
Public lands managers	0.0	5.9	9.8	7.8	13.7	6.7	10.1	18.0	4.5	20.2	<0.001
Scientific community	14.7	3.9	11.8	8.8	10.8	7.9	4.5	5.6	5.6	13.5	0.007
Where likely to seek info	*V*	*S*	*N*			*V*	*S*	*N*			
Other growers	56.9	33.3	9.8			31.5	36.0	32.6			<0.001
Extension agents	42.2	37.3	20.6			34.8	42.7	22.5			Ns
Extension publications	41.2	42.2	16.7			42.7	44.9	12.4			ns
Trade magazines	34.3	47.1	18.6			16.9	28.1	55.1			<0.001
Commercial suppliers	12.7	43.1	44.1			9.0	27.0	64.0			0.010
Consultants	7.8	27.5	64.7			11.2	29.2	59.6			ns
Internet	82.4	15.7	2.0			84.3	13.5	2.2			ns
Libraries	19.6	36.3	44.1			49.4	29.2	21.3			<0.001
Conferences	30.4	47.1	22.5			51.7	41.6	6.7			<0.001
***(V**ery important, **S**omewhat, **N**ot)*											
Frequency of interaction with farmers at job											
Daily (%)						8.0					
Weekly (%)						21.6					
Monthly (%)						19.3					
Seldom (%)						34.1					
Never (%)						17.0					

Discussion. As with any survey, responses represent an entire population only when participants are selected randomly out of the population. The participants in this study were not selected at random. Instead, the participants were selected using purposive sampling in which I acquired public lists of sustainable agriculture operations and pollinator scientists/managers and recruited off of those lists by selecting every entry with a working email address. Additionally, the survey announcement was placed on three relevant listservs and those respondents were cataloged into appropriate categories based on self-reported demographic and occupational characteristics. More than a quarter of potential participants who were recruited responded to the survey and although they could share similar viewpoints to those outside of the recruitment pool, their responses represent only those people who received a recruitment announcement and/or followed a listserv advertisement to the online survey site. In total, the responses represent 416 Mid-Atlantic sustainable agriculture operators and 211 pollinator scientists/managers.

Almost half of the producers in the sample were female, a finding inconsistent with Mid-Atlantic farm operators overall but not within the sustainable agriculture community (Gilbert *et al.* 2003; USDA 2002). Even so, it is important to consider the high percentage of women farmers when developing outreach materials because the target audience is no longer dominated by men (SSI 1998). Not surprisingly, age range was not different between the two groups. Additionally, it would be expected that more scientists and managers have significantly more advanced degrees than producers. Even so, education did not explain the high proportion of respondents in both groups that believed only 11 to 100 species inhabited their county, even though estimates are much higher for most locales in the Mid-Atlantic. Education also did not influence respondents' selection of preferred terms for non-honey bees indicating that knowledge about native bees is not necessarily obtained from academic sources, although it could be a source for some.

Both groups equally disliked the term *wild bees* to describe non-honey bee pollinators, an interesting finding given that in the scientific literature, *wild bees* is commonly used in title and subject fields of peer reviewed articles. When asked what the term *wild bees* conjured up for farmers during informal interviews, I learned that for several producers the term brings to mind "killer bees" and invokes a sense of fear or danger. Also interesting is the equal treatment of both groups toward *pollinating bees* and *pollen bees*, the former being dramatically preferred over the latter even though these terms are most similar in language out of the list. It is also intriguing that scientists and managers would rank *pollinating bees* so high (in second place) even though the term does not necessarily exclude the introduced European honey bee.

Consequences of pollinator loss were ranked differently between producers and scientists/managers. Given that 36 percent of those producers who have hives (14 percent of all producers), either rented or owned, on their property believe that colony collapse disorder is affecting their hives, it is not surprising that overall producers rank loss of beekeeping higher than scientists/producers. An interesting finding is that scientists/managers overall rank loss of pollination of crops as less important even though the argument frequently touted by the scientific community is that pollinators help to provide at least one third of the foods we eat.

Responses regarding biodiversity also provided interesting results between the two respondent groups. More in the producers group believed that taxpayers should not be burdened with the costs of providing habitats for biodiversity and instead farmers were responsible for protecting biodiversity. It should be noted, however, that sustainable producers in general are likely more amenable to environmental stewardship on their lands. A survey addressed to conventional farmers might elicit a different opinion and further research about their opinions would be very informative. The majority of sustainable agriculture operators own their land which is in sharp contrast to conventional farmers, most of whom rent in this region. Tenancy could impact the farmer's sense of responsibility to the farm and influence the likelihood of protecting ecosystem services on rented property.

Even though farmers in the sample indicated a strong willingness to provide habitats for biodiversity in the absence of a green payment to offsets costs incurred to implement and maintain conservation practices, fewer scientists and managers believed that producers would be willing to do so. This is most likely a consequence of scientists and managers including both conventional and sustainable producers in their considerations. More frequently than sustainable operators, conventional farmers have enrolled in government programs to offset the costs of taking land out of production for the purpose of protecting wildlife and ecosystem services. Fewer sustainable agriculture farmers use government conservation programs to offset costs for maintaining biodiverse habitats on their farms. This could explain the discrepancy between what scientists/managers and sustainable producers think about green payments. Nevertheless if the misconception that farmers are unwilling land stewards, due to not being economically motivated, is prevalent in the scientific community as a whole, this could undermine constructive dialog between the groups and inhibit effective outreach.

The National Research Council report, *Status of Pollinators in North America*, recommends outreach to the agricultural community in order to teach them about the importance of pollinators (NRC 2007). The findings of the survey have varied implications for outreach. Trade publications, as important media for local producers, would want to target an increasing number of women producers. Scientists and managers would also want to consider the equivalent gender ratio when designing outreach materials. Outreach cannot be limited solely to publications and Internet resources because most farmers in the sample rely on other growers for information about pollination services. For this reason, it is imperative that scientists work more closely with farmers in developing demonstration projects on private lands that can help spread the word about the pollination research and practice. USDA's Sustainable Agriculture Research and Education (SARE) program, as well as other agri-environment foundations and NGOs, offer funding for these types of partnerships.

Out of the sample, the median annual cost to maintain honey bee hives for hive owners was US$110 and for hive renters was US$200. Pollinator-friendly habitats, depending on the intensity and extent, can be maintained for comparable costs so that native bees can supplement or replace honey bees for mixed fields if crop pollination requirements allow. Sixty percent of sustainable producers in the sample tilled their fields but only to a depth of 6.4 inches on average. Shallow tilling as opposed to deep tilling may reduce ground bee nest destruction (E. Julier, pers. comm.).

To help offset expenses of implementing pollinator-friendly habitats, there exist several USDA NRCS conservation programs such as the Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), Wildlife Habitat Incentives Program (WHIP), Environmental Quality Incentives Program (EQIP), Conservation Security Program (CSP) and the Comprehensive Stewardship Incentives Program (CSIP). Adding pollinator habitat recommendations to practices within these conservation programs would lead to more conventional farms being able to contribute to native bee conservation efforts. In terms of recommended future research, an investigation of the beliefs and values of conventional farmers in relation to pollinators would augment the results reported here for sustainable agriculture farmers by gauging farmers' interest in conservation practices that restore and maintain pollinator habitats since conventional farms account for the majority of cropped acres in the Mid-Atlantic region and elsewhere in the United States.

Chapter 8: Evaluation of Opportunities and Challenges to Native Bee Conservation in Mid-Atlantic Sustainable Agriculture

The purpose of this chapter is to evaluate opportunities and challenges to conserving pollinators in Mid-Atlantic sustainable agriculture. It has been suggested that the promotion of native pollinators on agricultural lands can bridge the conservation and food sectors of society (Nabhan 2001) because pollinators directly benefit both agricultural productivity through pollination of crops and ecosystem services through providing pollination services for uncultivated plants and as members of diverse ecological communities and food webs. My interest is investigating what factors contribute to the integrity of that bridge by examining the ecological, economic and cultural value of native bees. In this chapter I integrate findings from Chapters 5–7 to evaluate opportunities and challenges to native bee conservation, provide recommendations for conservation action and suggest future targeted research in specific areas where current knowledge gaps hinder progress. Additionally, I review my use of an interdisciplinary approach to valuing native bees and discuss its advantages and limitations.

Valuing native bees in Mid-Atlantic sustainable agriculture

Given that we do not conserve things we do not value, I investigated the ways in which humans value native bees. Not only are they economically valuable to us, but they also provide ecological and cultural benefits, yet to date their value has not been explicitly established in Mid-Atlantic sustainable agriculture. By assigning value to ecosystem services we, as humans, acknowledge the benefits we receive from our environment and therefore inherently acknowledge our strong dependence upon ecosystem services. We cannot develop value without first developing criteria for worth. It is in the development of worth that we need to understand the ecological, economic and cultural benefits that ecosystem services provide and this calls for an interdisciplinary approach. Just as we need ecological knowledge to develop markets for tradable ecosystem services and policies to regulate their protection, we need cultural knowledge to understand how stakeholders formulate decisions to protect or exploit ecosystem services and at what intensity (Kremen & Ostfeld 2005).

Conservation of pollinators in sustainable agriculture will depend on researchers finding answers to some basic questions about native bees. First, we need to know what pollinators are present on farms. We need to know which species of bees pollinate which varieties of crops, by how much, and at what economic return. We also need to know how to attract pollinators onto the farm and then attract them to the crop plant that needs pollination. We need to know what types of habitats are required to support native bees in and around farms. Paralleling the importance of research on the ecology and pollination biology of native bees and crops is the method of translating important research findings into farm management practices via outreach. We need to understand the likelihood of adoption of pollinator-friendly practices by examining the institutional structures that can provide incentives and the knowledge and interest of farmers to encourage bees on their farms. Research in Chapters 5–7 helps answer some of these questions.

A small subset of sustainable agriculture farms in the Mid-Atlantic region supports at least 81 species, as a conservative estimate being that species accumulation curves continued to increase and did not level off with increased sampling effort. Several common species dominate my bee collections while more than 50 species of few individuals were also found on farms. This reinforces the assertion put forth by Kremen *et al.* (2004) and other researchers that a large suite of bees will likely use farm habitats and that species compositions on farms are temporally and spatially dynamic through the growing season and among years. That sustainable agriculture farms exhibit such high numbers of different species also demonstrates their importance as refugia for biodiversity compared to conventional farms (Ahnstrom & Weibull 2005; Maestas *et al.* 2003). I investigated a select few companion plantings to assess their attractability to bees and found that as I predicted, different species of crop and cut flower exhibit different bee affinities. More experiments like this are necessary to build floral resource guides for farmers in this region. As a start, recent work in Delaware and Michigan has resulted in regional brochures that display floral resources that farmers can use to enhance bees on their farms (Isaacs & Tuell 2007; Sarver 2007).

In my pollination experiments I found that in these two particular varieties of two crop plants, bees did not enhance seed production or fruit size. Even so, there are hundreds of cultivars that have not been tested for their reliance on native bees for pollination. I have checked off two more on the list but more research is needed in larger experiments to be able to quantify the contributions of native bees to vegetables in mixed fields. The paucity of data available on native bee pollination contributions to individual crop species is one of the biggest impediments to assessing economic value.

Assessing their economic value is even more challenging because the basic ecology of native bees and their interactions with most crop plants is not well studied thus far. A recent estimate of the contribution of native bees to U.S. fruit and vegetable pollination is US$3.07 billion (Losey & Vaughn 2006). More research on specific crops will help to calibrate that estimate. According to the National Academies of Science recent report, *Status of Pollinators in North America*, the valuation of pollination services by native bees is contingent upon knowing the following: 1) specific need for animal pollination, 2) crop yield gain contributed by pollinator, 3) crop price, 4) cost of pollination services, 5) value of marketed byproducts (such as honey) and 6) availability of alternative means of pollination (NRC 2007). These are difficult data to collect and for some sustainable agriculture farmers without access to managed hives, native pollinators are invaluable so for them a dollar value might not be necessary. For the vast majority of producers, hand or mechanical pollination, as a substitute for animal pollination, is not a feasible or cost-effective alternative. Instead the best approach would be to maintain Mid-Atlantic's natural pollinator populations, e.g., native bees, in and around farms so that growers continue to receive a critically important environmental service for free.

Economic factors influence whether or not pollinator-friendly practices on farms are likely to be implemented on sustainable agricultural farms. The cost to famers of maintaining pollinator populations cannot outweigh the benefits gained from pollinator services, else the farmer has little incentive to change current management practices. Successful conservation is contingent on the ability to demonstrate that there exists a strong link between pollinator promotion practices and realized increases to agricultural productivity in the form of yield quality and quantity. In a recent paper published in *Environment and Development Economics*, the distinguished ecologist Paul Ehrlich asks ecological economists to ramp up their efforts to assess economic value for some of the most important ecosystem services and to provide results to policymakers (Ehrlich 2008). Collaborations between ecologists and ecological economists are essential so that each discipline can relate to the other what knowledge gaps are necessary to fill in order to provide such recommendations for decision-makers.

Given that pollinators provide a *direct* ecosystem service benefit to individual agricultural producers by way of pollination for their crops potentially resulting in improved yields, producers may view practices directed at pollinator promotion more favorably compared to practices directed at enhancing other ecosystem services. This is because other ecosystem services such as water quality, flood retention, carbon sequestration, *etc.* are farther removed from the farm, benefit the public good and only *indirectly* benefit the individual farm. My research on the perceptions of pollinators offers some clues on whether farmers view pollination as more important than other services. Producers ranked pollination as important to their farming operation yet ranked the service behind water and soil, an important consideration for the pollinator conservation advocate.

Also interesting is that almost all sustainable agriculture producers in the study believe farms were important places for biodiversity yet fewer scientists/managers believed this. This emphasizes the need for ecologists who work in agroecosystems to communicate to their colleagues that biodiversity protection should be applied universally over many land uses, not reserved for protected areas. In discussions with some ecologists at professional meetings I have noted what appears to be a cultural belief that biodiversity protection is best served by preserving tracts of land where land use is minimal. My survey aligns with that belief indicating that even though farms are documented to support diverse communities of species, for some ecologists farms do not fit well into their mental model of what lands targeted for conservation should look like. One ecologist emphasized that conservation on farms takes financial resources away from conserving biodiversity in more pristine places. This type of sentiment could hinder biodiversity conservation as a whole.

Conserving native bees in Mid-Atlantic sustainable agriculture

Assuming bee/crop ecology was fully understood and economic valuation was further along, there still exists the issue of translating value into conservation. It is true that we do not conserve things that we do not value but the converse is not necessarily true. Sometimes we value things but still do not conserve them. We choose other priorities ahead of conservation at times. For this reason, it is helpful to understand attitudes, beliefs and values that influence our rankings of priorities. Getting pollinator-friendly practices instituted across agricultural landscapes could be challenging if we do not understand potential barriers to adoption of practices.

A number of farmers are willing to participate in programs that take land out of agricultural production for the purpose of protecting environmental resources (USDA 2002); however, each farmer may be driven by different motivational forces (Jacobson *et al.* 2003). If a blanket conservation program is developed without an understanding of farmers' enrollment motivations, the program may attract few participants. It is entirely possible that in particular areas of a region, cultural differences among farmers may explain variation in adoption of conservation practices where economic factors show no influence (Beedell & Rehman 2000). This is because a range of factors influences adoption of conservation practices that protect ecosystem services (see Table 8.1).

Table 8.1. Factors that influence adoption of conservation practices.

Initial costs	Exposure to practice
Maintenance costs	Technological understanding
Labor requirements	Complexity
Timing of receipt of benefits	Reliance on tradition
Maintenance requirements	Perceived inappropriateness
Record keeping	Doubt in science behind practice
Lack of information	Aversion to government oversight
Perceived risk	

(Nowak 1992; Rogers 2003)

One of the barriers to adoption of conservation practices can be an aversion to government oversight. Tensions between regulatory agencies and farmers create a rift between environmental and agricultural interests. An example in Maryland highlights this disconnect in which farmers feel their livelihoods are threatened. Eighty-seven percent of farms in Maryland are family owned and the vast majority are smaller than 500 acres. The average age of the principal operator is 55.8 years and more than half of them farm as their principal occupation (USDA 2002). A policy aimed at protecting the Chesapeake Bay and its tributaries was adopted in 1998 that affected thousands of Maryland farming operations by requiring every agricultural operation with annual incomes greater than $2,500 or more than eight animal units (AU) to develop nutrient management plans. This legislation intensified tensions between farmers and resource managers (Paolisso & Chambers 2001) because science could not make a *direct* link between environmental degradation and individual farms. It would be helpful to be able to discriminate between opposition to government sponsored conservation programs on the one hand and disinterest in pollinator conservation itself on the other.

Results of my survey indicate that Mid-Atlantic sustainable agriculture producers are willing to implement pollinator-friendly practices on their lands without cost-share, a finding that scientists/managers might find surprising being that less of them thought farmers would be willing to promote pollinators without cost-share. Conventional farmers, who may not be as amenable to promoting natural habitats on their farms without cost-share, are also an important demographic to target in outreach efforts since their land base is far greater in the Mid-Atlantic compared to sustainable agriculture operations. Protection of ecosystem services and biodiversity on agricultural lands is typically limited by the amount of funding allotted to cost-share programs aimed at implementing conservation practices. For this reason, it is critically important to combine efforts and forge partnerships so as to spend financial resources efficiently. To protect pollinators, efforts should be geared toward finding conservation practices that simultaneously maintain agricultural productivity and provide for multiple ecosystem services, including pollination. Such USDA programs include the Conservation Reserve Program (CRP), Conservation Reserve Enhancement Program (CREP), Wildlife Habitat Incentives Program (WHP), Environmental Quality Incentives Program (EQIP) and the new Conservation Security Program (CSP).

The North American Pollinator Protection Campaign, a partnership between hundreds of scientists and natural resource managers, is driving much of the call for native pollinator conservation in the United States. Its Agricultural Programs Task Force is looking for ways to include pollinator conservation in conservation practices on farms.

Already NAPPC has encouraged legislatures to include language that protects and supports pollinators on agricultural lands and within NAPPC, the Agricultural Programs Task Force (formerly the Farm Bill Task Force) is working with NRCS to include pollinators in the language of broader conservation programs available to farmers within the Farm Bill.

Review of interdisciplinary approach

Whether it be one person trying to understand facets of multiple disciplines or multiple researchers in different disciplines collaborating on a research project, interdisciplinary research is incredibly important in the face of complex environmental problems that will plague us throughout the coming decades. We will never understand the value of native bees if we do not integrate the multiple ways that bees provide value. Evidenced by the publication of the National Research Council's report on North American pollinators and the more recent FAO *Rapid Assessment of Pollinators' Status* (FAO 2008; NRC 2007), pollinators are valued but we have not adequately articulated that value to ensure their protection. Their provision of a comprehensive set of recommendations for needed research and policy actions makes these reports invaluable tools for conservation advocates to build on existing efforts. Conservation efforts must be guided by interdisciplinary thinking so that native bee value can be made explicit.

An interdisciplinary approach to problem-solving is advantageous nevertheless there exist limitations that should not be overlooked. One major disadvantage of interdisciplinary research conducted by one person is that his/her depth of knowledge in any one field is not as great as for an individual expert within a field. In addition, institutional barriers at times prevent information exchange between disciplines. Knowledge acquisition in western cultures evolved out of a positivist approach that encouraged compartmentalization and as a result most academic institutions are divided into discrete learning centers according to discipline (Acutt *et al.* 2000). Even liberal arts colleges, with the goal of exposing students to various ways of thinking, retain their separate departments across the campus. Few institutions integrate departments to offer truly interdisciplinary courses, however, more colleges and universities, at least on paper, appear to be moving in this direction. Outside of academia, government agencies also are cordoned into distinct departments. Although this can prove efficient by way of housing experts with common knowledge in one place, it can hinder forward progression in knowledge transfer if interagency exchange is limited. Again, more interagency partnerships are evolving more recently as evidenced by the groups formed within the North American Pollinator Protection Campaign (NAPPC), although redundancy among government agencies remains, especially in collection and storage of pollinator data (IABIN 2007) but collaborations among groups have already begun to reduce that overlap (NAPPC 2008).

I end with an excerpt from Paul Ehrlich's message to ecological economists that encapsulates my sentiment about interdisciplinary research that tackles complex and challenging environmental problems (Ehrlich 2008):

> "Lest you think that as an ecologist I've been too demanding of ecological economists, let me assure you that my recommendations to ecologists are similar in direction. I, and numerous of my colleagues, think many ecologists are doing increasingly sophisticated investigations of increasingly trivial problems. In a contrasting minority, one distinguished ecologist has repeatedly said that those of his colleagues who have 'gone public' with their concerns about the human predicament are 'undermining the scientific discipline'. This obviously isn't true, since public interest in and support for ecology has only increased since ecologists helped people to become aware of environmental problems. But even if ecology were being 'undermined', that would be a trivial cost compared with the benefit of awakening humanity to its peril. Many ecologists continue

to pursue those trivial problems on the excuse that it is ‘curiosity-driven research’, and they also decline to get involved in ‘applied’ problems. This is a hangover from the past when science was divided by many into ‘pure’ (research with no immediate application to human problems) and ‘applied’ (that with obvious application). In those olden days, the most challenging science was thought to be pure, although there have been innumerable examples of pure science discoveries that later yielded practical applications. Nuclear physics is an excellent example — but the value of some of the applications is, to say the least, questionable.

Yet problems of trying to analyze and then deflect the potentially horrendous and interrelated consequences of human overpopulation and overconsumption by the rich minority — environmentally deleterious land-use change, biodiversity loss, toxification of Earth, global heating, and so on — are at least as basic and challenging as solving most apparently ‘pure’ scientific problems. A major test of any scientist’s skill and ability is what he or she chooses to be curious about. Good choices can either be something that helps to solve a pressing problem or research that greatly enhances our understanding of how the world works, even with no immediate connection to the human predicament. Much the same can be said of the science of economics, with the problems of ecological economics falling largely into the first category.”

Appendices

Appendix 1. Recruitment Emails for Pollinator Questionnaire

Initial Recruitment Email for Pollinator Questionnaire

Greetings!

As part of a larger research study, I have developed a questionnaire that seeks your opinions and views on the topic of pollinators in agriculture. I am gathering information from agricultural producers, land managers and scientists. I would like to ask you to take a few minutes to participate in the study by completing an online questionnaire that takes 5-10 minutes to complete. Your answers will be kept confidential and information gathered from the questionnaire will be pooled and not linked to any individuals. At the completion of the study, results will be available upon your request.

Soon you will receive an email from a web-based survey service, SurveyMonkey.com, that will provide instructions and a link to the online survey. You may also request a paper version of the survey by replying to this email with your mailing address. If you have any questions, comments or concerns, please feel free to contact me. Thank you in advance for your assistance!

Best regards, Annette Meredith

****
Annette M Meredith, PhD Candidate
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301.405.5886

Follow-up Email with Internet Link to Pollinator Questionnaire

Annette Meredith, a researcher at the University of Maryland, is collecting information about your views on pollinators in agriculture and your response would be appreciated.

Here is a link to the survey:
http://www.surveymonkey.com/s.aspx?sm=33ugoPYK_2fwEm6lUFKA0xJQ_3d_3d

This link is uniquely tied to this survey and your email address, please do not forward this message.

Thanks for your participation!

Please note: If you do not wish to receive further emails from us, please click the link below, and you will be automatically removed from our mailing list.
http://www.surveymonkey.com/optout.aspx?sm=33ugoPYK_2fwEm6lUFKA0xJQ_3d_3d

Reminder Email with Internet Link to Pollinator Questionnaire

I recently sent you a link to an online survey about your views on pollinators in agriculture. Although I have received completed surveys from respondents in your region, I'd like to invite your input into this process. Please take a few minutes to share your views by completing the following online survey:
http://www.surveymonkey.com/s.aspx?sm=Lfx75EMCYQBuVjJZPL8Gng_3d_3d

This link is uniquely tied to this survey and your email address, please do not forward this message.

Thanks for your participation!
Annette Meredith
University of Maryland

Please note: If you do not wish to receive further emails from us, please click the link below, and you will be automatically removed from our mailing list.
http://www.surveymonkey.com/optout.aspx?sm=Lfx75EMCYQBuVjJZPL8Gng_3d_3d

Appendix 2. Online questionnaire. Surveymonkey.com hosted the questionnaire. Questions in the first 5 sections were available to everyone. In section 6, *Agricultural Producer?*, respondents selecting *Yes* continued into next section through the section entitled *Tillage* and then were automatically directed to the last section, *Feedback*. Respondents answering *No* in section 6, *Agricultural Producer?,* were automatically directed to the section entitled *Pollinators*, skipping questions regarding farming characteristics.

Pollinators & Agriculture

Consent Form

This is a research project being conducted by Annette Meredith at the University of Maryland, College Park. I am inviting you to participate in this research project because you are involved in sustainable agriculture, pollinator research, or both. The purpose of this research is to identify cultural values and beliefs toward pollinators in an agricultural setting. This questionnaire will address perceptions about the likelihood and practicality of pollinator promotion being incorporated into existing agricultural conservation practices.

The procedures involve filling out a questionnaire on your opinions about pollinators and pollination of crops. The time required to complete the questionnaire is between 5 and 15 minutes. All information collected from participants in the project will remain confidential. The questionnaires are anonymous and will not contain information that may personally identify you. The names and contact information of all study participants will not be revealed or shared in public presentations or publications using the project's findings. Your information may be shared with representatives of the University of Maryland, College Park or governmental authorities if you or someone else is in danger or if we are required to do so by law. There are no known risks associated with participating in this project.

We hope that, in the future, people might benefit from this study through improved understanding of the benefits of pollinators to agricultural productivity. This research is not designed to help you personally, but the results may help the investigator learn more about the incentives and barriers to pollinator conservation in agricultural landscapes. Your participation in this research is completely voluntary. You may choose not to take part at all. If you decide to participate in this research, you may stop participating at any time. If you decide not to participate in this study or if you stop participating at any time, you will not be penalized or lose any benefits to which you otherwise qualify.

For additional information on this research program and your rights and benefits as a participant, please contact Annette Meredith (Researcher), 4321 Hartwick Road, Suite 300, University of Maryland, College Park, MD 20740; (email) meredith@mdsg.umd.edu; (telephone) 301-405-5886. If you have questions about your rights as a research subject or wish to report a research-related injury, please contact: Institutional Review Board Office, University of Maryland, College Park, MD 20742; (email) irb@deans.umd.edu; (telephone) 301-405-4212. This research has been reviewed according to the University of Maryland, College Park IRB procedures for research involving human subjects.

Your selection of "I consent" indicates that: you are at least 18 years of age; the research has been explained to you; your questions have been fully answered; and you freely and voluntarily choose to participate in this research project.

Continue?

- ◯ I consent
- ◯ I do not consent

Pollinators & Agriculture

Demographic Information

For each question, please use your mouse to click on the response that BEST reflects your situation or opinion.

If you need to leave the survey at any time, just click "Exit this survey." To re-enter the survey and continue where you left off, use the same survey link that you used earlier.

What is your age range?

- ◯ Under 21 years
- ◯ 21-30 years
- ◯ 31-40 years
- ◯ 41-50 years
- ◯ 51-60 years
- ◯ 61-70 years
- ◯ Over 71 years

What is your gender?

- ◯ Male
- ◯ Female

What is your primary occupation?

Occupation: ____________________

What is your highest education level?

- ◯ Less than 9th grade
- ◯ Grades 9-12, no diploma
- ◯ High school graduate or equivalency
- ◯ Some college
- ◯ Associates degree
- ◯ Bachelors degree
- ◯ Masters degree
- ◯ Doctoral degree

In what county and state do you reside?

County: ____________________

State: ____________________

Agriculture & Conservation

Please rank the following reasons for preserving agricultural landscapes. (Each ranking may only be used once.)

	Most important	2nd most important	3rd most important	4th most important	5th most important
To maintain a rural way of life	◯	◯	◯	◯	◯
To keep agricultural locally viable	◯	◯	◯	◯	◯
To decelerate land development	◯	◯	◯	◯	◯
To maintain sense of community	◯	◯	◯	◯	◯
To protect biodiversity	◯	◯	◯	◯	◯

Do farms provide important habitat for biodiversity?

◯ Yes
◯ No

Declines in animal (insects, birds, mammals) pollinator populations have been reported around the globe. Please rank the following consequences of pollinator loss. (Each ranking may only be used once.)

	Most important	2nd most important	3rd most important	4th most important
Loss in overall biodiversity	◯	◯	◯	◯
Loss in adequate pollination of crops	◯	◯	◯	◯
Loss of native plants that require animal pollinators	◯	◯	◯	◯
Loss of beekeeping as an industry	◯	◯	◯	◯

Are agricultural producers responsible for protecting biodiversity on their lands?

◯ Yes
◯ No

Should taxpayers pay agricultural producers to protect biodiversity on their lands?

◯ Yes
◯ No

Which of the following insects do you consider beneficial to agriculture? Select all

Pollinators & Agriculture

that apply:

- [ ] Adult ants
- [ ] Adult bees
- [ ] Adult beetles
- [ ] Adult butterflies
- [ ] Adult flies
- [ ] Adult moths
- [ ] Adult spiders

Please rate the following research needs:

	Very important	Somewhat important	Not important	Don't know
Colony collapse disorder	○	○	○	○
Economic benefit of pollinators	○	○	○	○
Agricultural pest control	○	○	○	○
Wild pollinator population censuses	○	○	○	○
Agricultural weed control	○	○	○	○
Disease transmission among pollinators	○	○	○	○
Effect of GM crops on beneficial insects	○	○	○	○

Pollinators & Agriculture

Bees & Pollination

Insects are responsible for most pollination with bees leading the effort as the dominant pollinator.

Honeybees, species *Apis mellifera*, were introduced to North America ~400 years ago by Europeans for purposes of pollination of agricultural crops and honey production.

Managed honeybees: Bees of the species *Apis mellifera* that are housed in hive boxes and managed by beekeepers and farmers for pollination and/or honey/wax extraction

Feral honeybees: Bees of the species *Apis mellifera* that live in unmanaged colonies in natural or artificial settings

Wild bees: Bee species other than European honeybees (*Apis mellifera*)

If conservation advocates wanted to promote the benefits of non-honeybee species to crop pollination, which term to describe these bees would be most appealing to you in publications, posters, outreach, etc?

- ◯ Native bees
- ◯ Non-*Apis* bees
- ◯ Pollen bees
- ◯ Pollinating bees
- ◯ Solitary bees
- ◯ Wild bees

In your estimation, how many different species of bees do you believe inhabit your county?

- ◯ 0 to 10 species
- ◯ 11 to 100 species
- ◯ 101 to 1,000 species
- ◯ 1,001 to 10,000 species

In general, are you afraid of bees?

- ◯ Yes
- ◯ No

Do you believe all bees have the ability to sting?

- ◯ Yes
- ◯ No

Pollinators & Agriculture

Do you believe Africanized or "killer" honeybees inhabit areas within your county?

- ◯ Yes
- ◯ No

Do you fear Africanized or "killer" bees?

- ◯ Yes
- ◯ No

Keeping in mind that yellow jackets are wasps, not bees, have you ever been stung by a bee?

- ◯ Yes
- ◯ No
- ◯ I'm not sure

Are you or anyone in your immediate family allergic to bee stings?

- ◯ Yes
- ◯ No
- ◯ I'm not sure

Pollinators & Agriculture

Outreach

Please indicate where you are likely to seek information about pollinators and pollination of crops.

	Very likely	Somewhat likely	Not likely
Other growers	○	○	○
Extension agents	○	○	○
Extension publications	○	○	○
Trade magazines	○	○	○
Commercial suppliers	○	○	○
Consultants	○	○	○
Internet	○	○	○
Libraries	○	○	○
Conferences	○	○	○

Who is responsible for distributing information about pollinators and pollination? Please rank. (Each item requires a ranking; 1=most responsible, 5=least responsible)

	1	2	3	4	5
Commercial suppliers & trade representatives	○	○	○	○	○
Extension agents	○	○	○	○	○
Individual farmers	○	○	○	○	○
Non-governmental organizations/non-profit organizations	○	○	○	○	○
Scientists	○	○	○	○	○

Which of the following groups need scientific information about pollinators and pollination the most? Please rank. (Each item requires a ranking; 1=most, 8=least)

	1	2	3	4	5	6	7	8
Agribusiness	○	○	○	○	○	○	○	○
Extension offices	○	○	○	○	○	○	○	○
General public	○	○	○	○	○	○	○	○
Government agencies	○	○	○	○	○	○	○	○
Individual farmers	○	○	○	○	○	○	○	○
Policymakers	○	○	○	○	○	○	○	○
Public lands managers	○	○	○	○	○	○	○	○
Scientific community	○	○	○	○	○	○	○	○

Pollinators & Agriculture

Agricultural Producer?

Do you SELL agricultural products that you produce such as food, fiber, fuel, feed, seed, flowers, wax, soap, etc.?

- ◯ Yes
- ◯ No

Bees & Pollination

Below is a list of pollinators sometimes found on farms. Please mark the ones that in your opinion are essential to your operation's ability to produce marketable goods. Check all that apply:

- ☐ Managed honeybees
- ☐ Feral honeybees
- ☐ Wild bees
- ☐ Butterflies
- ☐ Beetles
- ☐ Flies
- ☐ Ants
- ☐ Hummingbirds
- ☐ Bats
- ☐ N/A

On average, which of the following bees do you believe do most of the pollinating of crops in your agricultural operation?

- ◯ Managed honeybees
- ◯ Feral honeybees
- ◯ Wild bees
- ◯ N/A

Would it concern you if there were no wild bees on the property that you farm?

- ◯ Yes
- ◯ No

If it was demonstrated to you by a credible source that wild bees contribute to crop pollination and can increase revenues for your farming operation, would you want to increase the number of wild bees on the property that you farm?

- ◯ Yes
- ◯ No
- ◯ N/A

If you incorporate habitat for biodiversity (defined as the variety of organisms and species and their interactions) in your agricultural operation, should you receive a green payment for doing so?

- ◯ Yes
- ◯ No

If funding were made available, would you be interested in implementing pollinator-friendly practices for a payment that offsets your costs?

- ◯ Yes
- ◯ No

Would you be interested in implementing pollinator-friendly practices in the absence of a payment that offsets your costs?

- ◯ Yes
- ◯ No

Do you plant or maintain pollinator-friendly plants on the edges of your fields?

- ◯ Yes
- ◯ No

Pollinator Friendly Plantings

For you to plant or maintain pollinator-friendly plants on the edges of your fields, you would require:
Check all that apply:

- ☐ List of suitable plant varieties
- ☐ Planting instructions
- ☐ Maintenance instructions
- ☐ List of attracted pollinators
- ☐ Cost-share to purchase seed
- ☐ Cost-share to maintain floral strip
- ☐ Visit from technical expert

Pollinators & Agriculture

Nesting

Do you provide nesting habitat on your agricultural land?

- ◯ Yes
- ◯ No

Nesting Habitat

For you to provide nesting habitat on your agricultural land, you would require: Check all that apply:

- ☐ List of suitable nest structures
- ☐ Installation instructions
- ☐ Maintenance instructions
- ☐ List of attracted pollinators
- ☐ Cost-share to purchase supplies
- ☐ Visit from technical expert

Managed Bees

At any time of the year, do you have managed honeybee hives on your agricultural land?

- ◯ Yes
- ◯ No

Pollinators & Agriculture

Honeybees

If you OWN and/or RENT hives, what is your approximate annual cost to maintain honeybee hives on your agricultural land? (Please do not leave blank--enter 0 for no costs.)

Annual cost to own hives ($/yr): ______

Annual rental costs ($/yr): ______

Do you believe colony collapse disorder (CCD) is affecting your owned or rented honeybee hives?

- ◯ Yes
- ◯ No

Farming Characteristics

How many years have you run your agricultural operation?

- ◯ 0 to 5 years
- ◯ 6 to 10 years
- ◯ 11 to 20 years
- ◯ More than 20 years

Please rank the following in order of importance to your agricultural operation. (Each ranking may only be used once.)

	Most important	2nd most important	3rd most important	4th most important
Adequate water	◯	◯	◯	◯
Adequate soil amendment	◯	◯	◯	◯
Adequate pollination	◯	◯	◯	◯
Adequate pest/disease control	◯	◯	◯	◯

Over the past 3 years, on average how many acres did you use to produce goods each year?

- ◯ 0 to 5 acres
- ◯ 6 to 10 acres
- ◯ 11 to 20 acres
- ◯ 21 to 50 acres

○ 51 to 100 acres
○ More than 101 acres

Please indicate the acreage allotted to each item below in your agricultural operation:

	Less than 0.5 acres	0.5 to 1 acres	1 to 2 acres	2 to 5 acres	More than 5 acres	N/A
Cut flowers	○	○	○	○	○	○
Feed grains	○	○	○	○	○	○
Food grains	○	○	○	○	○	○
Fresh market vegetables	○	○	○	○	○	○
Hay	○	○	○	○	○	○
Orchard fruits or nuts	○	○	○	○	○	○
Seed	○	○	○	○	○	○
Pasture	○	○	○	○	○	○

How would you describe your agricultural operation? Check all that apply:

☐ Certified organic
☐ Pesticide free
☐ Herbicide free
☐ Fungicide free
☐ Conventional

Please rate the importance of each method in getting your products to consumers.

	Very important	Somewhat important	Not important
Community Supported Agriculture (CSA)	○	○	○
Farmers Market	○	○	○
Co-op	○	○	○
Restaurant	○	○	○
Processor	○	○	○
Grocery store	○	○	○
Floral shop	○	○	○
Retail store	○	○	○
Farm stand	○	○	○

Do you own farm land?

○ Yes

◯ No

Own

In what county and state do you own farm land?

County: __________

State: __________

Rent?

Do you rent farm land?

◯ Yes
◯ No

Rent

In what county and state do you rent farm land?

County: __________

State: __________

Till?

Do you till your cropland?

◯ Yes
◯ No
◯ N/A

Tillage

On average, to what depth do you till your cropland?

Depth in inches: __________

Pollinators & Agriculture

Pollinators

Below is a list of pollinators sometimes found on farms. Please mark the ones that in your opinion are essential to the production of marketable goods. Check all that apply:

- ☐ Managed honeybees
- ☐ Feral honeybees
- ☐ Wild bees
- ☐ Butterflies
- ☐ Beetles
- ☐ Flies
- ☐ Ants
- ☐ Hummingbirds
- ☐ Bats

On average, which of the following bees do you believe do most of the pollinating of crops in your county?

- ◯ Managed honeybees
- ◯ Feral honeybees
- ◯ Wild bees

Would it concern you if there were no wild bees on the properties that produce your food?

- ◯ Yes
- ◯ No

In your current occupation, how often do you interact with farmers as part of your job responsibilities?

- ◯ Never
- ◯ Seldom
- ◯ Monthly
- ◯ Weekly
- ◯ Daily

If it was demonstrated by a credible source that wild bees contribute to crop pollination and can increase revenues for farming operations, do you believe farmers would want to increase the number of wild bees on the property that

they farm?

- ◯ Yes
- ◯ No

If farmers incorporate habitat for biodiversity (defined as the variety of organisms and species and their interactions) in their farming operations, should they receive a green payment for doing so?

- ◯ Yes
- ◯ No

If funding were made available, do you believe farmers would be interested in implementing pollinator-friendly practices for a payment that offsets their costs?

- ◯ Yes
- ◯ No

Do you believe farmers would be interested in implementing pollinator-friendly practices in the absence of a payment that offsets their costs?

- ◯ Yes
- ◯ No

Please rank the following in order of what you believe to be important to farmers in your county. (Each ranking may only be used once.)

	Most important	2nd most important	3rd most important	4th most important
Adequate water	◯	◯	◯	◯
Adequate soil amendment	◯	◯	◯	◯
Adequate pollination	◯	◯	◯	◯
Adequate pest control	◯	◯	◯	◯

Pollinators & Agriculture

Feedback

Thank you for visiting the questionnaire website.

Please feel free to use this space to provide comments, feedback, or reactions to the questionnaire or any subject matter therein.

Appendix 3. Comments from Feedback box at end of online survey. Comments copied verbatim. Only personal information has been edited to protect respondent identities.

	Comment Text
1.	Very important work! We are using hand-tools (broadfork, hand spade) for tilling, so we don't disturb the soil much when we go 1 foot deep. Can't imagine life on earth without wild bees.
2.	This is a property of a non-profit organization, for which I am a manager.
3.	Believe a good farmer should be encouraging biodiversity on their land. In the ideal world, they should not have to be paid to do it.
4.	I'm sorry I was late in responding to your request to fill out this questionnaire. I work on native bee conservation issues here in Vermont, and would be happy to help you in any way I can on contacts with local farmers and other people involved with promoting and conserving pollinators. FYI, farmers in my area tend to be highly knowledgeable about farming, well educated, yet largely ignorant of the existence-- to say nothing of the importance-- of native invertebrate pollinators. Same story for the general public. Thanks. –[…]
5.	Thanks for the opportunity to participate in the survey. I do not have direct involvement in the farming community -- my responses reflect opinion only.
6.	I am working with a national group of agricultural leaders who are exploring the role of native pollinators in enhancing agricultural productivity and profitability. I'd be happy to visit with you about our findigs and recommendations if you are interested.
7.	Thanks for launching this potential research. It is much needed. We'd like to know of your results and progress. […]
8.	i did not like the "place things in order" questions.
9.	I do not live in the USA
10.	Thanks for your work. I answered these questions based on our cutflower/vegetable operation that is in the middle of the family farm owned by my partner. That farm is 300 acres and has been farmed by his family for ~300 years. We grow flowers and vegetables on ~3 acres, and that is the only part in which I am actively involved. If you'd like his input as the long-term farmer, contact him at […]
11.	Some questions I cannot answer reliably because I'm not American (e.g., honey bees are native to Africa) and others becaue I don't live in an intensive agricultural area.
12.	2007 will be our last year in business, so we will not participate other than completing the questionnaire. Best of luck with your research. The farm next to ours keeps bees, so I'm assuming our crops have been pollinated by both managed and wild bees.
13.	Shouldn't it be industry who ought to take more responsibility for destroying our pollinators?
14.	Thank you for the research. It is an important aspect to farming that most people today do not understand.

15.	We are producers of Natural 100% grass raised and finished beef. Our rented property has several stands of bees owned by a third party. My grand father had 64 stands of bees. We love honey and use it extensively in cooking. We appreciate being consulted relative to this important subject! Thank you!
16.	We grow U-Pick Blueberries, primocane raspberries and thornless and thorny blackberries plus fresh asparagus we pick.
17.	Thank you for the effort.
18.	Some of these questions were difficult to answer like ranking who needs information on pollinators the most. I believe everyone needs this information from Farmers to the Public to Land Managers. The ranking I gave to this question are somewhat arbitrary as I feel everyone should have access to this information if our attitudes and policies towards pollinators are to change.
19.	More recently I have been working with farmers that have an understanding and interest in encouraging pollinators on their land. They want to do hedgerows to divide fields and incorporate intergrated pest management. It is not yet the majority but as new people move onto the land so do new ideas.
20.	As far as I know, none of the beekeepers like myself who take good care of our bees, are certified organic or refrain from chemical solutions, have had CCD problems..in fact, I refer to CCD as "PPM" --Piss Poor Management.
21.	Our opperation is certified wild crops under USDA and we use the interent rather than face to face sales.
22.	I would like to see the return of the honey bees, It went from thousands last year to less than ten this year, honey bees are gentler than other pollinators. I can cut flowers in the field and they learn to go around me and to work with me, thus making it safer for those working in the field, it's also easier to predict weather by watching thier behavoir, other pollenators cling to the product or worse get irritated such as the bumble bee, or buzz around your head like the smaller wild bee. It's been an unhappy and less productive year. good luck with your research.
23.	I think the general public needs to know about the importance of pollinators and the impacts of excessive use of insecticides have on all pollincators. Biodiversity is critical.
24.	We sharecrop bees with a beekeeper, taking a percentage of the honey for sale.
25.	Good survey and i hope it helps. […]
26.	The questions were not very good, so the answers won't be very meaningful. You need to put a spot for explanations with each question.
27.	Suggest look at the Swiss example for payments for conserving biodiversity. Great examples.
28.	Like all surveys there were questions that had gray areas that are more important than black and white answers. Space for comments under each question is advisable. If the researcher wants to continue in this line of work I would advise a working understanding of the subject matter.
29.	I manage an organic farm. A local honey producer needed a place to keep his hives, i needed bees for pollination, so it helped us both. They have been there for about 5 years.
30.	I hope this helps!
31.	Thank you for the opportunity to contribute toward this study.

32.	Many of the questions expect monolithic answers. If you inert "most" or "many" as qualifiers in my answers, they better reflect my thinking.
33.	business is combination of agriforestry and wild harvesting.
34.	This season I have really noticed a decrease in fruit set county wide and I believe lack of pollinators is responsible for a large part of this. The general public needs more education on responsible pesticide use to protect our pollinators and natural enemies.
35.	I grow a large fraction of food for my household and buy a significant amount of the remaining at a farmers market.
36.	Do you know of a good, but reasonable speaker on this topic in the Minnesota or Wisconsin area? I'm working with a team of folks interested in local food system dev't and we're organizing a fall event near Rice Lake, WI. We're looking for a speaker to talk on this issue for a group of 75-100 people. Please email me at […] Thank you, […]
37.	Please keep me informed of any developments in the area of wild pollinators. My e-mail address is […]
38.	I read something wrong early on - read country instead of county for the first few pages and couldn't go back without deleting later answers, which I didn't want to do. So first questions which say "county" are answered with "country" in mind.
39.	Hope it's helpful. Not sure since I don't really deal with farmers in my day-to-day work.
40.	Public awareness is key to any action by farmers, policy makers, or agibusiness themselves. They will not change what they do not know needs changing. However, money does talk!
41.	I live in DC -- there are no farmers in DC, although there are garderners. Therefore, my responses to questions about "farmers in my county" should be "not applicable" but that was not a choice available.
42.	We have a upick operation. Are you familiar with the work being done with smaller foundation cell size to combat mites and DCS?
43.	I am a sideline beekeeper.
44.	Not sure what you mean by feral vs wild bees.
45.	I hope I did the rankings right - the ones that had rankings of 1 to 5 or more didn't tell me what scale to use, so I used #1 as the highest ranking.
46.	In some cases it was difficult to rank answers, since I believe the options are equally important! By giving an option a last-place ranking doesn't mean it's not very important to me...
47.	I had an anaphylactic reaction (as verified by a hospital) to honey bees stings after working with bees for 3 years. I apparently outgrew it 10-20 years later.

48.	It should be noted at the beginning of the survey that there will be an opportunity to provide comments. There were several questions which I was required to answer which I either would not have answered because they were not relevant to my operation, or needed qualification. Now at the end of the survey I do not recall where there were issues without going back through the survey. For example, regarding tillage, some of our crops are raised using no till (without herbicides, but with cover crops). Yet other crops require tillage to a depth of 5 to 6 inches whereas others require deeper tillage - depends on the crop. Also the comment about which insects are important for pollination of crops doesn't include their role in seed dispersal or other ecological roles (as in certain woodland botanicals in which a large number of species are dependent on ants for seed dispersal even though ants which are generally insignificant pollinators. Hummingbirds are important as pollinators though not for our specific crops, but they can be considered important to our crops by virtue that they play some role in biodiversity. The same is true for beetles which tend to pollinate flowers adapted to beetles. At least one of our crops is exclusively beetle pollinated though I didn't check beetle pollination to be generally important to the large marjority of our crops.
49.	Mpst of the land i farm is in hay now. i am in process of up grading the fertility without doing lot of plowing planting. i pasture and make hay on most of the land i farm.
50.	Please pay chemical farmers cash to convert to organic. Ban endoclrine disrupting herbicides like Atrazine, manufactured by Swiss company Syngenta and already banned in Europe. It causes frogs in the wild to be born two sexes. A nurse told me babies are born two sexes also. I then read about it on the Internet. Lead also causes it. Lead solder was used on my copper pipes in my house in 1975. We have an acid neutralizer to prevent lead absorption. Thank you.
51.	Please provide me with a copy of the report for which the date I provided is being used. […]
52.	Some of the rankings were very difficult to place and may be a little misleading related to how I really feel. Some were very clear and easy to answer.
53.	We are not a cert. organic, herbicide free, fungicide free, nor conventional. We IPM to determine if it is economic to spray. 90% of our acres are no-till with cover crops on all of our vegetable crops.
54.	Great questionnaire - I look forward to seeing the results when they are published. best wishes […]
55.	We are a sustainable farm. We use the leaset amount of pesticides nessesary to produce a quality product and we farm in harmony with nature.
56.	I previously was a produce farmer, most of the farmers in my area already adhere to some practices which will not destroy the bees. We have to rent bees in order to get a good yield and to get good pollination results.
57.	Biodiversity seemed to be an important question topic, however, I do not recall seeing a definition for it except some parenthetical statement late in the survey. I think the results may be skewed with different views on what biodiversity means from an agricultural perspective (versus the "Amazon jungle" view).
58.	berry farm ,fruit trees,no honey bees here for 15 years ,hive here now,insects and wild bees did pollinating until now

59.	Good survey, but you didn't ask if I have hives or know of people who have hives
60.	Some of the questions are a bit confusing, because the word "important" may have a negative and a positive connotation. I assumed a positive connotation. Adult beetles may be very important PESTS of crop, and adult bees may be very important POLLINATORS. The meaning is the opposite.
61.	More work could be done concerning A. mellifera nutritional requirements and how those needs are met by various crop pollens. I wonder if the trend towards monoculture cropping may lead to malnutrition in honeybees. Is there any way to find out some of the results of your survey? i.e. What other beekeepers might think important.
62.	The omission of solitary and social wasps for pest control, and for a contribution to pollination, is very serious. The wordings could be improved.
63.	I feel "colony collapse disorder" is a phrase being used to generalize all honey bee losses. In fact, it has been known for quite some time that many factors are at critical levels and acting in various combinations can have various symptoms that lead to lethal consequences. The emphasis that has been placed on finding the "mystery" cause has overshadowed work that has been done on the actual causes. CCD has been used to gain media attention and political support and funding. Additional research funding was needed, but it disturbs me that it required such a dramatic and sensationalized approach to get it. Maybe more scientists should employ this technique to acquire funding for worthwhile research.
64.	Good luck!
65.	Nowhere did you mention the problem of the use of chemicals contributing to the probelms with the bee decline. Both commerical and residential need to chenge their ways.
66.	You ned more open-ended space within questions. Beetles, for instance. There are far more harmful beetles than beneficials in our area. Beneficials are fine. The harmful ones can devastate crops. Survey leaves no way to distinguish.
67.	Any financial assistance to add to the number of bee hives I could have would be most welcome.
68.	www.[...].com
69.	As a cut flower grower, we don't want pollinators on our farm. A polinated flower dies to produce seed. Not what a cut flower grower wants.
70.	Thanks for your work. See http://www[...]
71.	most of our pollination is done by various species of bumblebee and native "sweat" bees. We do not till the areas where they live and grow flowering herbs to attract and feed them. We have seen 2 honeybees this year and even the wild bees were late to appear. Believe the flooding last June may have had a detrimental effect.
72.	none

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