PROJECT SUMMARY

Instructions:
The summary is limited to 250 words. The names and affiliated organizations of all Project Directors/Principal Investigators (PD/PI) should be listed in addition to the title of the project. The summary should be a self-contained, specific description of the activity to be undertaken and should focus on: overall project goal(s) and supporting objectives; plans to accomplish project goal(s); and relevance of the project to the goals of the program. The importance of a concise, informative Project Summary cannot be overemphasized.

Title: Importance Of Native Bees In Northeastern Apple Production And The Factors That Maximize Their Pollination Services

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The production of fruits and many vegetables is dependent on successful pollination. Honey bees are the most widely used crop pollinators but declines in honey bee populations over the past 50 years makes it imperative that we explore the utility of alternative crop pollinators. Apples are an important crop in the US and successful apple production requires insect pollination. Preliminary results suggest that native bees are providing economically important levels of apple pollination in the eastern US. Native bees are both abundant and diverse in apple orchards, and previous studies indicate that some native bee species are more effective pollinators than honey bees on a per-visit basis. We will investigate the role of native bees in apple pollination by examining, first, the impact of orchard size, management, and surrounding landscape on native bee species richness and abundance. We will characterize bee species in terms of pollinator effectiveness using per-visit pollen deposition experiments. We will then relate species richness, abundance, and per-visit effectiveness to fruit set in order to identify conditions under which the native bee fauna is providing sufficient pollination services. Finally, we will develop management practices for the maintenance and enhancement of native bee populations in the apple orchard ecosystem. Our studies will provide recommendations on how growers can maximize apple pollination by managing the local native bee fauna rather than relying on increasingly expensive honey bee rentals. Our results will lead to more sustainable practices for apple pollination, lower costs of production, and will have a positive impact on the environment and human health.

Project Narrative

Introduction

Pollination is an essential step in production of most fruits and many vegetables. An estimated 35% of the global production of plant-based food comes from crops that benefit from animal pollination (Klein et al. 2007). Bees are by far the most important pollinators in agricultural settings and contribute between $5.7 to $19 billion per year to the United State economy (Levin 1983; Robinson et al. 1989a,b; Southwick and Southwick 1992; Morse and Calderone 2000) and $217 billion per year globally (Gallai et al., 2008). The most widely-used bee for crop pollination is the European honey bee, *Apis mellifera*. Honey bees are ideal pollinators in many crop systems. Each colony produces thousands of foraging workers and colonies can be moved into orchards and fields during the flowering period. They are especially important pollinators in large scale, highly disturbed agroecosystems (the Central Valley of California, for example). However, honey bee populations in North America and Europe are experiencing declines (Aizen & Harder 2009), primarily due to heavy pathogen and parasite loads (Ratnieks & Carreck 2010). The progressive decline of honey bee populations in North America over the past 50 years (Committee on the Status of Pollinators 2007; Aizen & Harder 2009), and the dramatic loss of honey bees due to colony collapse disorder (CCD) in 2007 (Oldroyd 2007; Van Engelsdorp et al. 2007) suggest that the exclusive reliance of agricultural pollination on one bee species remains extremely risky.

While honey bees are important crop pollinators, they are certainly not the only crop pollinators (Committee on the Status of Pollinators 2007). Native bees (species of bees that are native to North America) play an important, but underappreciated, role in crop pollination. The economic contribution of our native bees to agricultural pollination is almost certainly high, but has rarely been quantified (Winfree et al. 2007, Ricketts et al. 2004, Kremen et al. 2002). It is very difficult to experimentally separate the role that native bees vs. honey bees play in crop pollination. More and more evidence suggests that the contribution of native bees to agriculture is often substantial, yet under-appreciated and poorly understood (Free 1993; MacKenzie & Eickwort 1996; Cane 1997; Delaplane & Mayer 2000; Kremen et al. 2002; Javorek 2002; Klein et al 2003a, b; Shuler et al. 2005; Morandin & Winston 2005; Greenleaf & Kremen 2006a, b; Losey & Vaughn 2006; Winfree et al. 2007, 2008; Julier & Roulston 2009).

Apples are an economically important crop in the United States that is likely pollinated substantially in some areas and under some conditions by wild, native bees. Surveys of apple orchards over the past century have indicated that orchards provide viable habitat for a surprising diversity of wild, native bees, particularly species in the genera *Andrena*, *Bombus*, *Halictus*, *Lasioglossum*, and *Osmia* (Hutson 1926; Phillips 1933; Brittain 1933,1935; Loken 1958; Free 1964, 1966; Kitamura & Maeta 1969; Gardner & Ascher 2006). Such native pollinators provide pollination services for "free" in many cases and may serve as "insurance" against declines in honey bee populations across the United States (Winfree et al. 2007). A number of studies indicate that native bees may be *better* apple pollinators on a per-visit basis than honey bees. Native bee species have been shown to carry more pollen (Kendall & Solomon 1973), to carry more compatible fruit pollen (Kendall 1973), to transfer fruit pollen at a higher rate (Thomson & Goodell 2001), to yield higher fruit set per visit (Vicens & Bosch 2000a), and to show a stronger preference for *Malus* flowers than honey bees (Kendall & Solomon 1973, Johnson 1984, Vicens

& Bosch 2000a). However, no previous studies have attempted to quantify the potentially important role of native bees in apple pollination.

Our project will focus on characterizing the community of native bees in apple orchards in the eastern United States. We will examine the interactions between orchard management, the composition of the bee community in each orchard, and the impact of this community on fruit set (Fig. 1). Our project will be the first attempt to examine the role that the native bee community plays in commercial apple production in the eastern United States. We will identify how management practices, such as pesticide/herbicide use, impact the species richness and abundance of native bees in apple orchards. We will also examine the impact of both bee abundance and bee species richness on the level of fruit set. Such information is essential for advising growers on how to effectively manage the local bee fauna in a sustainable and economically beneficial way. Our study will result in specific guidelines for growers on effective management of native bees for commercial apple pollination.

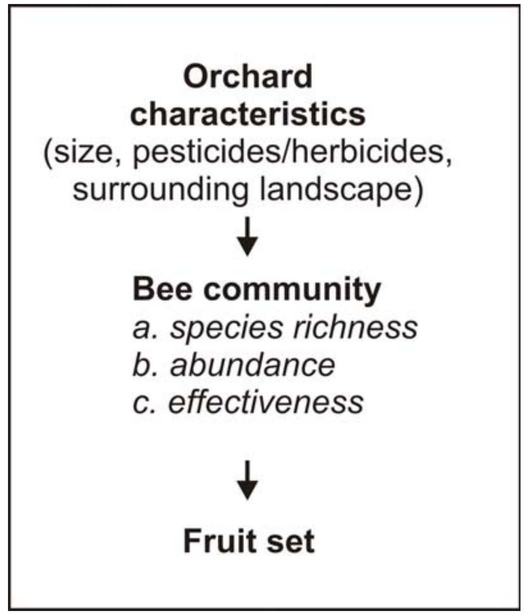

Fig. 1: Project organization.

Project goals

- Characterize the bee community in eastern US apple orchards in terms of *species richness, abundance* and *per-visit effectiveness*.
- Examine the impact of orchard size, pesticide/herbicide use, and surrounding landscape on the composition of the native bee community (species richness, abundance, and per-visit effectiveness).
- Examine the impact of bee community composition on *fruit set* in commercial apple orchards.
- Distinguish the relative contribution of native bees and honey bees to apple pollination.
- Develop explicit recommendations on the management and maintenance of native bees in apple orchards.

Rationale and Significance

1. Economic value of apples in the United States

Based on data from the USDA National Agricultural Statistics Service for 2008 (the last year for which economic data are available), apples are the second highest value non-citrus fruit produced in the United States. Apple production in 2008 was valued at $2.19 billion, second only to grapes ($3.34 billion) and very close to almonds ($2.26 billion). The total bearing acreage for apples in the US was 350,090 acres. A total of 4,884,700 tons fresh weight was produced in 2008.

Apples are an important crop in New York State. New York is the second largest producer of apples (following Washington State) in the United States with an average of 25 million bushels of apples produced annually by a total of approximately 694 commercial growers and annual sales reaching $261 million (USDA NASS, 2008; http://www.nass.usda.gov/). In New York there are approximately 43,000 acres in apple production. Approximately 17,000 people work in the handling, distribution, marketing, processing and shipping of apples in New York. Apple production in New York State is concentrated in three main areas: the Hudson River Valley in southern NY (30%), the Champlain Valley in northeastern NY (10%), and the Lake Ontario shore from Oswego to Buffalo (60%) in central NY.

2. Pollination biology of apples

The following account is based primarily on McGregor (1976, and references therein) and Faust (1989). Commercial apples (*Malus domestica*) are perennial trees anywhere from 10 feet to over 40 feet in height. Most new orchards employ dwarf or semi-dwarf trees (<10 feet in height) because they can be planted more densely and the fruit can be more easily harvested. There are over 7500 varieties of apples produced worldwide, but 90% of the apples produced in the United States are derived from approximately 15 varieties. Leading varieties include Delicious, Golden Delicious, Empire, Granny-Smith, McIntosh, Fuji, Gala, and Jonagold.

The apple flower consists of five radially arranged petals, 20-25 erect, pollen-bearing stamens, and five stigmas united in a common style (McGregor 1976). The ovary contains five compartments, each divided into two ovules, giving rise to 10 radially arranged seeds when fully pollinated. Apple flowers are grouped into clusters of about six flowers on a 1-3 year-old woody shoot. The primary, or "king", bud usually opens first and generally produces the choicest fruit. If the king bloom fails, the lateral blooms can also produce marketable fruit. Most growers use various thinning methods (either physical or chemical) to remove smaller, mostly lateral, fruits prior to harvest. The average bloom period for apple is about 9 days, but this can be shorter when the weather is warm and dry, or longer when the weather is cool.

Apple flowers produce both substantial nectar and pollen rewards for pollinators. Many social bees, including honey bees and bumble bees, are primarily nectar foragers, whereas most solitary bees are primarily pollen foragers. All apple cultivars are largely self-incompatible, so that successful apple pollination requires cross-pollination, usually ensured by inter-planting of multiple varieties. The usual practice is to ensure good pollination through management of bees and other pollen vectors, and then apply chemical thinners to selectively abort the smaller fruit and optimize the market value of those apples that remain. Usually, the more seeds that develop in the apple, the larger, and therefore higher value, it is (Murneek & Schowengert 1935).

3. The role of native bees in apple pollination

While honey bees are generally viewed as essential pollinators in apple orchards (McGregor 1976, Free 1993), there is evidence that other bee species are contributing significantly to apple pollination. Kendall & Solomon (1973) analyzed the amount and composition of pollen carried on a variety of insects collected visiting apple blossoms in the UK. They counted (1) the total number of pollen grains present on the body, and (2) the proportion of pollen grains that were from Rosacaeae (they lumped *Malus*, *Prunus*, *Crataegus* and *Amelianchier* together because they could not be separated morphologically). Honey bees ranked

11th out of the 20 bees tested in the quantity of Rosaceae pollen carried (roughly 4000 grains/worker). A number of other bee species, mostly in the genera *Andrena*, *Bombus*, and *Osmia* carried significantly more Rosaceae pollen than honey bees. Among the top three species were *Andrena pubescens*, *Andrena haemorrhoa* and *Andrena coitana*, with between 16,000 and 24,000 grains of Rosaceae pollen per bee. These bees are either equal to, or smaller than, worker honey bees, so this effect is not due simply to differences in body size. Most bee species in the survey carried between 60 and 90% Rosaceae pollen and the above three *Andrena* species carried between 81% and 97% Rosaceae pollen, suggesting a high level of Rosaceae specialization. The results of this study suggest that, while honey bees are certainly capable of effective apple pollination, there were 10 species of native bees that carried more Rosaceae pollen, on a per-bee basis, than honey bees.

In a related study, Kendall (1973) examine pollination effectiveness of various bee species in apple orchards. Bees were collected, killed, and the venter of the bee was brushed against a test (virgin) stigma. He measured the percentage of ovules fertilized by honey bees, six species of bumblebees (*Bombus*), eight species of *Andrena*, and one *Osmia*. As controls he used stigmas cross-pollinated by hand, self-pollinated by hand, and un-pollinated. The highest pollination rates were achieved by two species of *Andrena* (*A. haemorrhoa* and *A. jacobi*), which proved to be significantly better than honey bees. In addition, species of *Andrena*, *Halictus*, and *Osmia* showed less variation *among orchards* in pollinator effectiveness than honey bees. Kendall concluded that "when abundant, female solitary bees must be valuable as cross-pollinators, and some species such as *Andrena haemorrhoa* and *A. jacobi* are consistently better pollinators of the flowers they visit than are similar numbers of honey bees." While the methods used in this study are simple, they provide evidence that native bees are no worse and, in some cases better, as fruit pollinators than honey bees.

Thomson & Goodell (2001) performed a much more rigorous analysis of pollinator effectiveness by examining both pollen removal and pollen deposition *per visit* by live honey bees and bumblebees. While *Apis* and *Bombus* removed similar amounts of pollen per visit, *Bombus* deposited slightly more pollen on stigmas per visit than *Apis*. Pollen collecting bees of both species removed more pollen per visit than nectar collecting bees. *Apis* showed a fairly high frequency (up to 30%) of "sideworking" (approaching nectaries laterally without contacting either stigma or anthers). These visits resulted in significantly lower levels of pollen deposition than regular visits.

Finally, detailed studies of non-*Apis* managed apple pollinators, such as *Osmia*, suggest that on a per-bee basis, *Osmia* females are significantly more effective than honey bees in apple pollination. Vicens & Bosch (2000a) compared per-visit fruit set by foraging female *Osmia cornuta* and honey bees in commercial orchards in northeastern Spain. One third of the *Osmia* visits resulted in commercial fruit set – a five-fold higher rate than for *Apis* visits. *Apis* foragers made little contact with the stigma, primarily because the majority of *Apis* floral visits (97%) were for nectar rather than pollen. In addition, *Osmia* foragers visited more flowers per minute and showed a strong preference for *Malus* pollen. Related studies (Vicens & Bosch 2000b) showed that *Osmia* females forage at lower ambient temperature than *Apis*. Other *Osmia* species have been shown to be better apple pollinators than *Apis* in Japan (*O. cornifrons*; Maeta & Kitamura 1974) as well as in the US (*O. lignaria*; Torchio 1985).

Together these studies suggest that native bees likely play an important role in apple pollination. However, only one previous study (Thomson & Goodell 2001) has directly measured *per-visit* pollen deposition and no previous studies have measured the relative abundance of native bees in apple orchards, making it difficult to quantify the overall contribution of native bees to apple pollination. Our survey of New York apple growers (see below) revealed a high level of interest in native bees as apple pollinators and a demand for information on how best to manage and maintain native bee communities in apple orchards.

4. Grower interest regarding native bee pollinators

In May, 2009 we conducted a survey of the approximately 690 commercial apple growers in New York state in collaboration with USDA National Agricultural Statistics Service, New York Field Office. This initial survey of New York apple growers provides baseline information on current management practices, knowledge and willingness to enhance wild bee pollination in apple orchards. Our survey included 24 questions related to grower practices and perceptions about native bees as pollinators. An initial survey was conducted by mail with additional respondents contacted by phone. A total of 262 growers in 43 counties responded to all or part of the survey. The survey included statistics on the size of the orchard, the management practices used (conventional, IPM, or organic), and the number of apple varieties grown. Growers surveyed provided a spatially representative sample of New York as shown by comparing percent apple growers by county from 2009 census data and percent respondents by county. Growers employed a variety of pest management regimes, with the majority using Integrated Pest Management (IPM, 65%), followed by conventional (25%), and then organic (10%).

Grower reliance on honey bees for pollination depended on farm size. Among growers with more than 100 acres in apple production, 96% always rented honey bees for pollination. Conversely, in apple orchards with under 10 acres, 73% of growers never rented honey bees. Considering larger farms rent more bees, it is not surprising that the proportion of growers who deemed honey bee rentals to be a major expense increased also with farm size. Sixty percent of growers with less than 50 acres of apple production had at one time considered relying exclusively on wild bees, but the same proportion of growers, 63%, with over 100 acres had not.

Concern over reliable pollination and support for the importance of wild apple pollinators were both high. Recent declines in honey bee populations due to CCD were considered a threat to successful apple production by 59% of New York apple growers. Native bees were viewed by 85% of surveyed growers as valuable pollinators. In spite of widespread appreciation for native pollinators, however, knowledge of the biology and diversity of wild bees was low. About 75% of NY apple growers said there were 10 or fewer wild bee species that visit apple. In our first year of field surveys, we identified over 70 species of bees in the 11 orchards studied (see below). Whether all 70 are important pollinators remains to be determined, but many species look identical to the untrained eye. Little to no extension information is available to growers about native pollinators in apple.

Willingness on the part of growers to enhance native pollinators was also high. 68% of NY apple growers said they would consider adopting low-cost land management practices to increase the diversity and abundance of bees in their orchards. The top criteria for doing so included cost, effectiveness, effort, and insurance that practices did not harm honey bees.

Already, 93% growers consider impacts on pollinators when using chemical treatments. Thirty percent of NY apple growers were familiar with alternative managed apple pollinators (such as the mason bee), but only 2% have ever used them. This reflects a gap on the east coast for alternatives to managed honey bees.

Throughout NY state, there is overwhelming support for the importance of wild pollinators and willingness to adopt practices for maintaining their populations. This applies to growers in all counties surveyed, it applies to orchards of various sizes, and it applies to growers who practice conventional, organic and IPM methods. A major impediment to grower reliance on native bees as pollinators is the lack of information on the diversity of native bees, their nest-site requirements, and specific management practices that would allow for long-term maintenance of their populations. Information on managed alternative pollinators and wild pollinators are currently not readily available for apple growers on the east coast. There was clear evidence that in larger orchards, growers are less likely to rely exclusively on native bees. Whether this is because native bees are less effective in larger orchards or whether this reflects economic considerations, such as the risk associated with crop loss due to insufficient pollination, remains to be seen.

Program Area Priority addressed: *Understand the environmental and biological processes that affect the abundance and spread of agriculturally important insects*.

Our project directly addresses this Program Area Priority because we will investigate the environmental and biological process that lead to successful fruit pollination in apple and other orchard systems. We will identify what management practices promote both the diversity and abundance of native pollinators and how these management practices translate to successful pollination of a high-value crop.

In addition, our project addresses one of the four challenges identified by the National Research Council's Board on Life Sciences committee report entitled "New Biology for the 21st Century: Ensuring the United States Leads the Coming Revolution". The committee recognized four challenges, one of which is to "*Understand and sustain ecosystem function and biodiversity in the face of rapid change*". Our project directly addresses the role of biodiversity (native bees) in maintaining and sustaining an important ecosystem function (pollination).

Approach

I. A general framework for examining pollinator communities and their impact on plant reproduction

Total pollination services provided by any one species (T_i) is a function of two factors: (1) *visitation rate* (I_i; the frequency of visitation to flowers of the crop species), and (2) *per-visit pollinator effectiveness* (P_i; single-visit contribution by a flower-visitor to the reproduction of a plant; usually measured as *pollen transfer* per visit or *fruit set* per visit; sensu Ne'eman et al. 2009). Visitation rate can be viewed as the "quantity" of pollination provided by any one species and the contribution to pollination per visit can be viewed as the "quality" of the pollinator

(Herrera 1989).

Total pollination services provided by species "i" can then be summarized as:

$$T_i = P_i \times I_i$$

Quantifying I_i and P_i is not trivial. I_i is usually measured as the number of flower visits per unit time (Parker 1981; Sugden 1986; Steffan-Dewenter & Tscharntke 1999; Tepedino et al. 1999; Kremen et al. 2002; Klein et al. 2003a, b; Ricketts 2004; Larsson 2005; Sahli & Conner 2006; Winfree et al. 2007, 2008) but can also be approximated as relative pollinator abundance (Herrera 1987, Olsen 1996). Some studies have collected data on *both* visitation rate and abundance (Herrera 1989, Winfree et al. 2008). P_i is even more difficult to estimate because it involves determining, for each species, the number of pollen grains deposited per visit (Herrera 1987, Kremen et al. 2002, Ricketts 2004, Larsson 2005, Winfree et al. 2007), the number of seeds set per visit (Parker 1981, Montalvo & Ackerman 1986, Olsen 1996, Steffan-Dewenter & Tscharntke 1999, Klein et al. 2003a), or both (Madjidian et al. 2008).

For large pollinator communities (>10-20 species), it is very difficult to obtain sufficient data for accurate measurements of per-visit effectiveness (Vázquez et al. 2005). Indeed, a number of studies have suggested that pollination services (T_i) can be approximated reasonably well by visitation rate alone (I_i; Winfree et al. 2008), because the variation in pollinator effectiveness/visit is low relative to the variation in visitation rate (Vázquez et al. 2005). What this means is that, while there may be variation among species in per-visit pollinator effectiveness, this variation is often low relative to the variation in abundance among species within the community (Parker 1981, Montalvo & Ackerman 1986, Sugden 1986, Herrera 1987, Olsen 1996, Klein 2003, and Larsson 2005).

One can also quantify the total effectiveness of a *pollinator community* by summing the pollinator services provided by each species present at a particular locality (Ne'eman et al. 2009). The total pollination services of a fauna of pollinators is the sum of the individual pollination services provided by each individual species (i = 1, 2, 3, 4, ... n):

$$\sum_{i=1}^{n} Ti$$

We will use a community-level analysis of pollinator services (sum T_i) in order to compare the variation in pollinator services among orchards, as well as to determine the relative importance of honey bees vs. native bees in apple pollination.

A major goal of our study is to distinguish the relative importance of native bees *vis-a-vis* honey bees in apple pollination. This is difficult to do because honey bees are ubiquitous in most agricultural settings and it is impossible to selectively exclude honey bees from visiting apple flowers. The framework outlined above will allow us to separate the relative contribution of native bees and honey bees to apple pollination. This is an important first step in assessing the potential impact of honey bee declines on crop production in the United States. We describe below our methods for characterizing the bee community in apple orchards for both components of T_i, visitation rate (I_i) and per-visit interaction effect (P_i).

II. Methods and preliminary data

1. Measuring bee species richness and abundance of native bees in apple orchards (I_i)

The methods we describe below were developed over two collecting seasons (2008 and 2009) in surveys of apple orchards in New York state. By *species richness* we mean number of bee species present at a site, and by *abundance* we mean the number of individuals of each species collected per unit of effort (time). All collections will be made between 9:00 and 15:00 on days when the air temperature exceeds 60 ^{o}F. Bees will be netted flying near apple blossoms or landing on apple blossoms, which means our measure of abundance will be closely correlated with visitation rate. We developed two different collecting methods, both of which provide information on bee species richness, and one of which provides information on bee abundance.

General collecting: consists of walking along rows of apple trees and netting any bees we observe landing on or flying around apple blossoms. We will not collect honey bees during this type of survey and our goal is to characterize the bee species richness in each orchard.

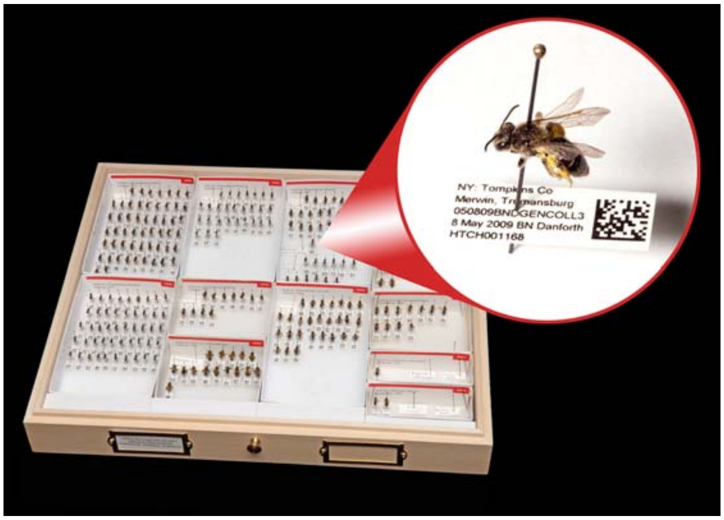

Fig. 2: Labeled, barcoded, and curated specimens showing unique barcode label and specimen identification number.

Time-trial collecting: consists of collecting all bees (honey bees and native bees) during 15-minute intervals. For 15 minutes we will walk down a single, 100m row of apple trees and collect any bees observed. The 15-minute timed collections give us information on bee abundance (numbers of individuals of different species) per unit time as well as species richness. Timed collections will allow us to compare both overall bee abundance among orchards as well as the relative abundance of native vs. honey bees within orchards.

For both methods, bees will be killed in cyanide killing jars, stored in labeled collecting vials, and later mounted on insect pins. For all collections we will record locality (and latitude/longitude), apple variety, time of day, weather conditions (temperature, cloud cover, wind speed), and collector. Specimens will ultimately be labeled with a unique barcoded label (containing a unique specimen identification code) which also includes standard insect label information, such as state, county, locality, date, collector and host-plant (Fig. 2). Specimens will be determined to species using relevant taxonomic keys to bees of eastern North America (e.g. Mitchell 1961a,b; Bouseman & LaBerge 1978; LaBerge 1971, 1978; LaBerge & Bouseman 1973, Rehan & Richards 2008), the Discover Life website, or by comparison with authoritatively identified specimens in the Cornell University Insect Collection. To track specimens and manage collection data we will use a relational database specifically designed for biotic survey work (*Biota 2.04*; Colwell 2006 [http://viceroy.eeb.uconn.edu/Biota]). Data from Biota can be easily exported for analysis in other programs, such as Excel, Access, and EstimateS (see below).

Estimating species richness (i.e, the *actual* number of species present at a site) is not a trivial task. The problem is that the number of species collected may underestimate the total number of species because rare species are, by definition, hard to detect. How can one know that a site has been adequately sampled and that the observed number of species approximates the actual number of species present? We will address this issue by using statistical methods and software (*EstimateS*; Colwell 2009) to compute the estimated number of actual species based on sample-based rarefaction curves (Gotelli & Colwell 2001, Ellison et al. 2007, Chao et al. 2009). Upper and lower 95% confidence intervals on species richness can be calculated using re-sampling algorithms. These species richness estimators can be used to assess the thoroughness of the sampling at each site (Chao et al. 2009) as well as to compare species richness among sites (Chao 1987). EstimateS can also be used to compare *similarity* among orchards in the composition of the bee fauna (using various measures of shared species including Jaccard's index of similarity and Chao-Jaccard abundance-based measure of similarity [Chao et al. 2005]).

In many pollinator diversity studies, species identification is a major obstacle because of the large number of species, lack of good reference material, or lack of taxonomic expertise. The PI is a bee taxonomist with over 20 years experience identifying bees of eastern N. America, which facilitates our ability to accurately determine specimen identities. In addition, our access to the Cornell University Insect Collection provides us with a tremendous resource for species identification. In 2009 we collected over 3000 specimens and identifications were completed in six weeks.

Preliminary results: Bee abundance

We used the number of bees collected/minute in our 15 minute "time-trial" collections as a measure of bee abundance. We used multiple 15-minute samples at the same site to calculate the mean and standard deviation on bee abundance (bees/minute) at each orchard. We compared samples collected by different people on the same day at the same site in order to assess whether there were substantial differences either in the overall bees/min or the ratio honey bees to

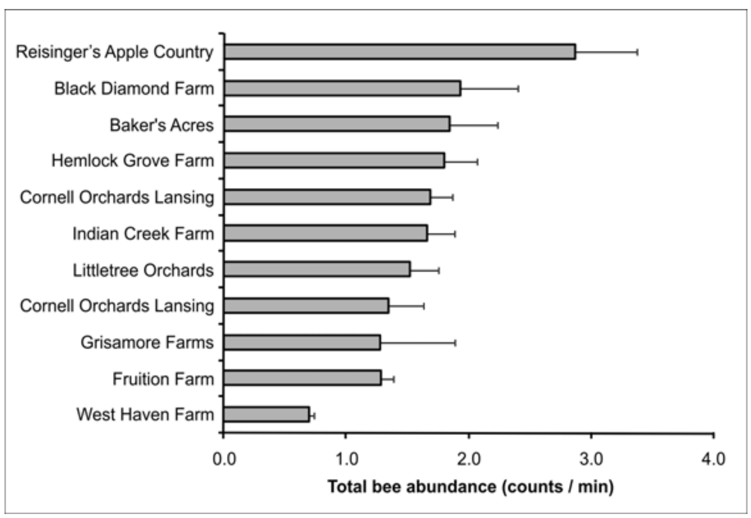

Fig. 3: Variation in bee abundance (total bees per minute) across the 11 orchards sampled.

native bees. We found no evidence of significant collector bias.

Our data from 11 orchards (2 organic and 9 conventional) sampled in 2008/2009 indicated significant heterogeneity in bee abundance across orchards for (1) total bee abundance (Fig. 3), (2) abundance of honey bees alone (Fig. 4), and (3) abundance of native bees alone (Fig. 4). For nine of eleven orchards, native bees outnumbered honey bees while at two orchards (Grisamore and Fruition Farm), honey bees slightly outnumbered native bees (Fig. 4). Honey bees were absent (based on our sampling) from one organic orchard (West Haven Farm).

Preliminary results: Bee species richness

Across all 11 orchards sampled in 2008/2009, we collected a total of 3000 specimens and obtained a total of 71 bee species (69 of which were native species). This is twice the number of bee species collected in an earlier study in the same area of New York (Gardner & Ascher 2006) and roughly 8 times the number of species estimated by the growers we surveyed (see above). The number of bee species detected varied among orchards from as few as 17 (CU Ithaca) to as many as 41 (Fruition Farm).

We used EstimateS to estimate the number of species for our overall sample and for each individual orchard sampled. For our overall sample across all 11 orchards and 114 collection events our observed number of species came close to the number estimated by EstimateS (Fig. 5), indicating that our sampling methods are effectively capturing the bee species richness in the orchards surveyed. For individual orchards the estimated number of species was similar to the observed number of species in most cases (Fig. 6). However, some orchards (e.g., Grisamore, CU Lansing) obviously need more thorough sampling. Overall similarity in bee species composition among the 11 orchards based on the Chao-Jaccard abundance-based estimator was 0.767, indicating an approximately 25% turnover (on average) in the bee fauna among orchards. The use of both species accumulation curves and diversity indices will allow us to explore variation among orchards in species diversity as well as identify orchards that need more thorough sampling.

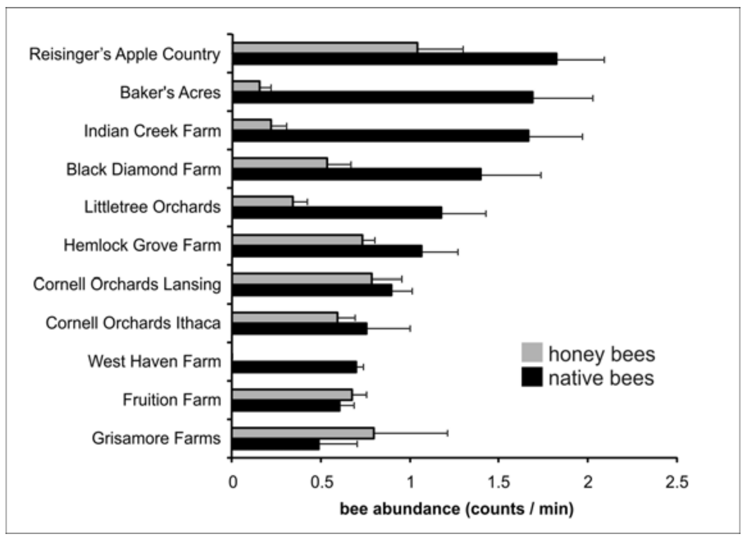

Fig. 4: Relative abundance of honey bees and native bees in the 11 orchards sampled. Note that native bees outnumber honey bees at nine of 11 orchards.

Our initial estimate of 70-80 bee species in just 11 apple orchards in central New York is a remarkably high number when compared to similar studies of bee species richness in agricultural settings. The number of bee species reported from recent agricultural surveys ranges anywhere from 8 to 54 (Blanche et al. 2006; Chacoff & Aizen 2006; Gemmill-Herren & Ochieng 2008; Greenleaf & Kremen 2006b; Julier & Roulston 2009; Klein et al. 2003a; Kremen et al.

2002; MacKenzie & Eickwort 1996; Potts et al. 2001; Ricketts 2004; Winfree et al. 2007, 2008). The largest number of species (54) was actually from a two-year surveys across 29 farms in New Jersey and Pennsylvania representing four crop species (muskmelon, pepper, tomato, and watermelon; Winfree et al. 2008). All other studies focusing on single crop systems obtained <50 species. We excluded from this analysis surveys using only pan traps (e.g., Tuell et al. 2009) because these surveys sample all bees, not just those actually visiting the crop flowers. Bee diversity in apple orchards may be particularly high because orchards, unlike some other agricultural settings, provide abundant resources (pollen and nectar) on a regular basis over many years. Such a long-term, stable resource may allow large natural populations of pollinators to be maintained.

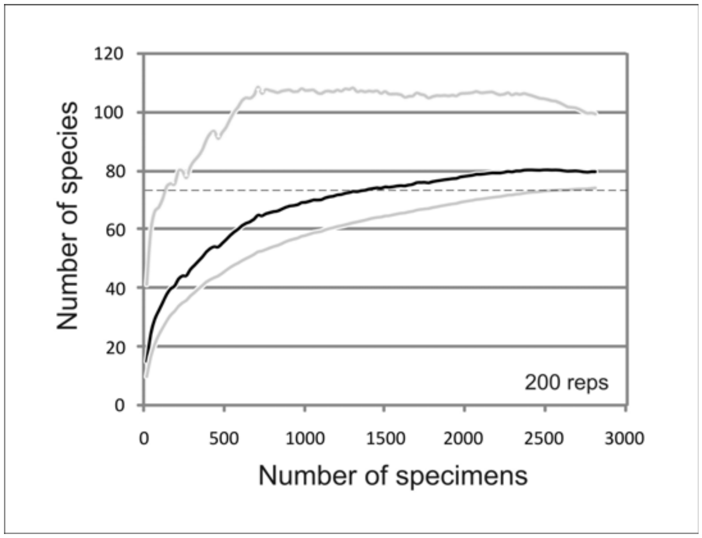

Fig. 5: Sample-based rarefaction curve for all 114 individual collections across all 11 orchards. Black line indicates the estimated number of species based on the Chao 1 estimator (Chao 1987). Gray lines indicate the upper and lower 95% confidence intervals. Horizontal dashed line indicates the actual number of bee species collected.

2. Measuring per-visit pollinator effectiveness (P_i)

Measuring per-visit pollination effectiveness (P_i) is challenging, especially when there are over 70 species one would (ideally) like to test. In addition, the apple bloom is extremely short (~ 9 days at each site), which limits the time over which we can collect data on pollination effectiveness of each species. As pointed out by Vázquez et al.(2005), "Conducting experiments to measure interaction strength among pairs of species may be feasible for small assemblages, but it is prohibitive for larger assemblages such as those normally considered in studies of interaction networks." Indeed, for most studies in which pollen deposition (or seed set) have been estimated on a per-visit basis, the number of species has been in the range of 10 or fewer (Parker 1981, Sugden 1986, Olsen 1996, Madjidian et al. 2008) or groups of closely related species have been lumped together into less than 10 "functional groups" (Montalvo & Ackerman 1986, Kremen et

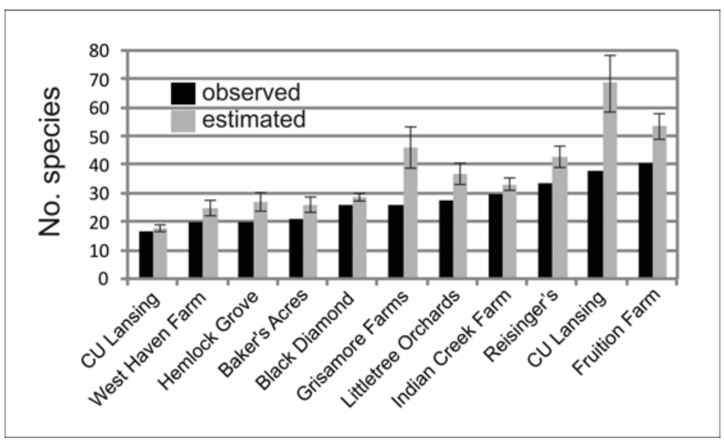

Fig. 6: Observed (black bars) and estimated (gray bars) numbers of species at each orchard based on sample-based rarefaction using the Chao 1 estimator (Chao 1987) with standard error bars.

al. 2002, Larsson 2005, Winfree et al. 2007; but see Herrera 1987).

We will use methods developed by Thomson & Goodell (2001) to determine the number of pollen grains deposited per visit by the bee species included in our study. Because of the large number of species (70-80 species; see above) and because it is difficult to identify live, foraging bees to species, it will be necessary to group bee visitors into functional groups in order to have sufficient sample sizes for estimating pollinator effectiveness. We will use the following functional groups: (1) *Apis*, (2) *Bombus* (all bumblebees combined), (3) large *Andrena* (mostly subgenera *Plastandrena*, *Melandrena* and *Andrena*), (4) small *Andrena* (mostly subgenera *Trachandrena*, *Scrapteropsis*, *Larandrena*, and *Simandrena*), (5) *Osmia*, (6) *Colletes*, (7) metallic halictid bees (mostly in the genera *Agapostemon* and *Augochlora*), and (8) non-metallic halictid bees (mostly in the genera *Lasioglossum* and *Halictus*). Such functional groups can be reliably identified during a short floral visit. To measure pollen deposition on a per-visit basis, we will present virgin flowers to foraging, female bees at the end of a 0.5 m stick. Before presentation, anthers will be carefully removed to avoid self-contamination of the stigma (as in Thomson & Goodell, 2001). After a visit by one bee, the stigma will be removed with clean forceps and placed in a drop of melted glycerine jelly tinted with basic fuchsin on a microscope slide (Beattie, 1971). A cover slip will be gently applied to distribute the pollen grains into a monolayer. Every pollen grain will be counted using a Zeiss compound microscope at 200-400x magnification. *Malus* pollen will be distinguished from alternative pollens using resources for pollen identification listed in Sipes & Tepedino (2005). Only *Malus* pollen grains will be counted. Sample sizes in the Thomson & Goodell (2001) study ranged from 13 to 70 replicates. We will perform at least 30 replicate tests for each functional group of bee pollinators for a total of at least 240 data points.

3. Quantifying overall pollinator effectiveness on a community-wide level (T_i)

In order to characterize the overall, community level pollinator effectiveness at each orchard we will combine our measures of abundance from each orchard with our measures of individual pollinator effectiveness (by functional group) to create a composite value for the overall pollinator effectiveness at the community level. This will be done in Excel (or MATLAB) by calculating the relative abundance of each species at a site (as measured by number of bees collected per minute in our 15-minute time-trial collections; I_i) times the per-visit pollinator effectiveness (measured as the average number of *Malus* pollen grains deposited per visit; P_i). The overall contribution of each species will then be summed to create a total value of the pollination services provided at that orchard (sum T_i).

This measure (sum T_i) has a number of interesting properties. It provides a quantitative measure of the potential pollinator effectiveness at each site that combines abundance of bee species and their per-visit pollen transfer rate. It can be used to quantify the relative importance of native bees *vis-a-vis* honey bees to overall pollination services. For example, one can calculate the proportion of the total pollinator services provided by the sum of all native bee species vs. the total pollinator services provided by honey bees alone. This is a useful measure for our purposes because the response of different bee species to variation in orchard features (e.g., size, pesticide use, surrounding habitat) may not be the same (e.g., see Williams et al. 2010). We predict that native bees will be more significantly impacted by orchard size and/or surrounding landscape features than honey bees. We will be able to test this hypothesis using the community-wide measure of overall pollinator effectiveness.

4. Selecting and characterizing orchards

The impact of farm management and landscape-scale effects on the pollination services provided by native bees is of great interest both to the scientific community as well as to fruit and vegetable growers. Pollinator communities are clearly sensitive to a number of factors, including habitat loss, fragmentation, agricultural intensification, pesticide use, and fire (see reviews by Ricketts et al. 2008, Winfree et al. 2009, and Williams et al. 2010). Understanding the factors that affect pollinator communities is essential for developing good management practices in the face of declining honey bee abundance. We will examine three potentially important correlates of bee community composition: (1) orchard size, (2) pesticide/herbicide use, and (3) composition of surrounding landscape. We will conduct most of our surveys in western New York (primarily Wayne County), which includes 60% of the apple acreage in the state. We will also include sites in the Finger Lakes region (primarily Tompkins County).

We will identify ~30 orchards for bee sampling ranging in size from <2 acres to >200 acres. We will work closely with Jim Eve, Eve Farm Services (see attached letter of support) to identify orchards of appropriate size and management practices as well as the county and regional Cooperative Extension offices (http://nysipm.cornell.edu/fruits/fruit_pgms/default.asp). Our goal will be to identify paired orchards which are matched in terms of size but which differ in terms of pesticide/herbicide use and surrounding landscape. Because orchard size and management practices are often correlated (conventional orchards are usually larger than organic orchards) this may not be easy. If we cannot match every orchard with a paired orchard of similar size, we can still analyze both orchard size and management practice by treating size as the independent variable and then analyze residual variation associated with management practice. While our surveys will be conducted primarily in New York state, these sites are representative of orchards in the eastern United States and it should be possible to generalize our results across much of the eastern US.

a. orchard size

Orchard size is an obvious correlate for us to examine. As orchards increase in size the relative proportion of the orchard that is in the vicinity of surrounding habitat will decrease. In addition, our grower survey (see above) indicated a strong tendency for orchard size to impact the perceptions of growers about the need for managed honey bee colonies. Orchards above roughly 50 acres tended to almost always rent honey bees and tended to be disinclined to rely

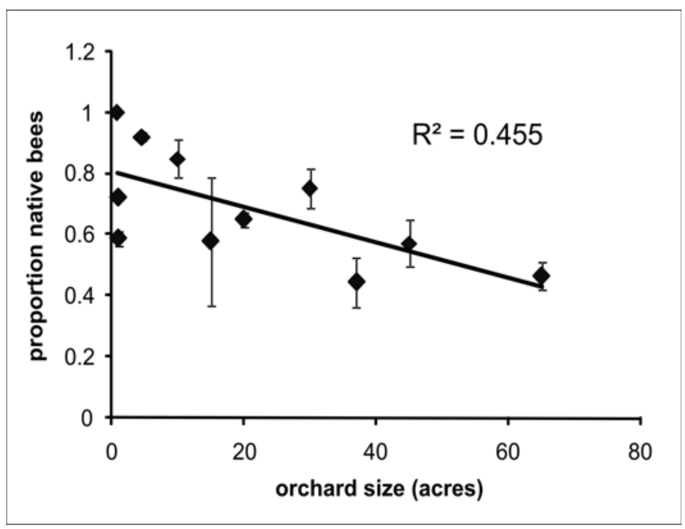

Fig. 7: Relationship between orchard size and the relative proportion of native bees in each sampled orchard.

entirely on native bees for apple pollination, while orchards of less than 50 acres tended to be more inclined to rely entirely on native bees for pollination services, and rarely rented honey bee colonies.

We will use orchard size, as determined both by aerial photographs and Google Earth images and information from growers to determine the number of acres of apple orchards are under cultivation at each site. We will identify orchards of various sizes ranging from <2 to >200 acres. Our preliminary data for orchards in the Finger Lakes region ranged from ~2 acres to 65 acres. Based on an analysis of our preliminary data for 11 orchards, we found a clear decrease in the relative abundance of native bees in larger orchards (Fig. 7), suggesting that orchard size may indeed be related to the pollinator effectiveness of the native bee community.

b. pesticide/herbicide use

Pesticide use can negatively affect bee abundance and species richness in agricultural settings (Kevan 1975, Johansen 1977, Plowright et al. 1978, Plowright & Rodd 1980, Gels et al. 2002, Shuler et al. 2005). Winfree et al. 2009, in a meta-analysis of 54 published studies on bee abundance and diversity, found that pesticide use had a slight negative impact on bee abundance, but only three studies had relevant data on pesticide use and the effect was not significant. Some studies have shown that bee species differ widely in susceptibility to pesticides, so that data on toxicity to honey bees may not be accurate for all bee species (Thompson & Hunt 1999). Scott-Dupree et al. (2009) investigated the toxicity of several widely used pesticides (imidacloprid, clothianidin, deltamethrin, spinosad, and novaluron) on three different bee species (*Bombus impatiens*, *Megachile rotundata*, and *Osmia lignaria*) and found as much as a 65-fold difference in sensitivity among species. Virtually nothing is known about the impact of herbicides on bee abundance and diversity because no previous studies have examined herbicide use.

Based on our grower survey, apple growers are acutely aware of the importance of minimizing pesticide/herbicide use during the flowering period. However, there is substantial variation among orchards in the extent and type of pesticides used. We will also analyze herbicide use because herbicide use has the potential to significantly impact ground-nesting native bee species. We predict that heavy use of herbicides with high toxicity to bees will have a very serious negative impact on ground-nesting, native bee species richness. Some commonly used herbicides (e.g., glyphosate, trade-name *Roundup*) appear to have relatively low toxicity to bees (at least honey bees).

We will characterize pesticide/herbicide use in two ways. First, we will ask growers to personally characterize the orchard management practices that they employ. Three options include organic, IPM, and conventional. The majority of apple growers in our state-wide survey (see above) described themselves as IPM (65%), followed by conventional (25%), and then organic (10%). We believe this is a representative sample of growers across NY state because the proportion of respondents in our survey from each of the top 10 counties in New York state mirrored closely the proportion of apple growers across the same counties (data not shown).

Second, we will collect pesticide use records from growers on an annual basis and calculate the environmental impact quotient (EIQ; Kovach et al. 1992a,b) for each orchard. While other methods for assessing the overall environmental impacts of pesticides exist (Levitana et al. 1996, van der Werf 1996, Reus et al. 2002), EIQ was specifically developed for use in the fruit and vegetable industry in New York State and appears well-suited to our purposes of classifying orchards in terms of the overall levels of pesticide use. Total EIQ values have been determined for commonly applied pesticides by experts, based on harm to human health, potential to pollute groundwater, and toxicity to beneficial insects and wildlife (Kovach et al. 1992a,b). Additionally, each pesticide is assigned a bee toxicity score. A farm's final EIQ rating will be calculated by summing, across all pesticides used, the product of a pesticide's EIQ score, concentration of active ingredient, and application rate (quantity per acre) throughout the season:

$$\text{Final EIQ score} = \Sigma \text{ EIQ Field Use Rating} = \Sigma \text{ EIQ} \times \% \text{ active ingredient} \times \text{rate}$$

We could also estimate the final EIQ for select periods of time, such as the window around the apple bloom period. Additionally, we will compare the ability of final EIQ scores and cumulative bee toxicity scores to predict observed bee species richness and abundance.

c. surrounding landscape

The importance of surrounding habitat on native bee species richness and/or abundance has been shown in a number of crop systems. Kremen et al. 2002, showed that the level of pollination services provided by native bees (as measured by visitation rate) was significantly affected by the proximity of farms to natural habitat. These differences in the pollinator fauna also translated into differences in pollen deposition rates (Kremen et al. 2002). Similarly, Ricketts (2004) showed that both bee diversity and visitation rate in coffee plantations were positively correlated with proximity to native forest fragments. The increased abundance and diversity of bees also resulted in increased seed set, increased seed mass, and decreased frequency of "pea-berries" (partially pollinated coffee beans; Ricketts et al. 2004). In addition, visitation rate by native stingless bees dropped more rapidly than visitation rate by honey bees as distance to undisturbed forest increased.

The above studies as well as several recently published meta-analyses (Ricketts et al. 2008, Winfree et al. 2009, Williams et al. 2010) all suggest that the composition of surrounding habitat has a strong impact on the composition of the local bee fauna. We can directly test this prediction in apple orchards by combining our measures of bee abundance and species richness with analyses of the landscape composition surrounding orchards.

We will characterize the landscape surrounding the surveyed orchards using methods described in Williams & Kremen (2007) and Winfree et al. (2008). We will use input data from the Cornell University Geospatial Information Repository (CUGIR; http://cugir.mannlib.cornell.edu/), an online repository in the National Spatial Data Clearinghouse program. CUGIR provides geospatial data and metadata for New York State, with special emphasis on natural features relevant to agriculture, ecology, natural resources, and human-environment interactions. We will create land-cover maps from aerial photographs to determine the percent of natural habitat (e.g., forest, meadow) within 0.5 km, 1 km, and 2 km (i.e., the local landscape) and 20 km (i.e., regional scale) radii of the orchard margins. We will use the percentage of natural habitat as an independent variable in multivariate analysis of variance of measures of bee species richness, abundance and effectiveness (see below).

5. Measuring fruit set

We will characterize the pollination services at each orchard in terms of mean fruit and seed set by marking/labeling a random sample of 20 branches per orchard with at least 50 blossoms prior to bloom. For each branch, we will record branch diameter and total number of flowers as these metrics can be correlated to fruit set (Ian Merwin, personal communication). Once fruits start to develop, 1-2 weeks after anthesis, we will count the number of flowers that set fruit and, for a subset of the fruit obtained, we will examine the number of seeds set per apple. Both measures will help us quantify the level of pollination services at each orchard. By combining these two measures we will be able to calculate the proportion of seeds set per experimental branch and the average seed set per farm by averaging across the 20 selected branches. Similar methods were used to analyze fruit set in Australian shrubs (Cunningham, 2010), a neotropical arum *(Spathiphyllum friedrichsthalii;* Montalvo & Ackerman 1986), and highland coffee (Ricketts et al. 2004). In all cases, there was a significant impact of bee abundance and/or diversity on the measures of fruit and seed set.

6. Analyzing interactions among orchard features, bee communities, and fruit set

We describe below the methods we will use to explore interactions among orchard features (size, pesticide/herbicide use, surrounding landscape), composition of the local bee community (in terms of abundance, species richness, and overall pollinator effectiveness), and fruit set.

a. Orchard features ➟ bee community

Our goal is to identify what impact orchard characteristics have on the composition, abundance and overall pollinator effectiveness of the local bee community across orchards. We will use a variety of methods, including principal components analysis, multivariate analysis of variance (MANOVA), multivariate regression, and descriminant functions analysis, to explore and characterize the impact of orchard characteristics on descriptors of the local bee community. We will also use non-parametric tests when the data violate assumptions of normality. Response variables will consist of measures of the local bee community, including the total number of species (actually collected as well as estimated based on species accumulation curves), the abundance of bees (I_i; bees collected per minute), and the estimate of the total community pollinator effectiveness (sum of T_i for each orchard). For multivariate analysis of variance we will include the following continuous, independent variables: orchard size, surrounding land use (% natural area within 1km of the orchard margin), and EIQ values. We will explore interactions among these variables using multivariate regression, MANOVA, and, when necessary, Spearman's rank order correlation coefficient.

We will also use the growers self-described management practices (conventional, IPM, or organic) to test the hypothesis that management practices impact the local bee fauna by examining if there are significant differences in abundance, species richness, or per-visit effectiveness among orchards of differing management regimes. This can be done using T-tests as well as descriminant functions analysis. We predict that orchard size and pesticide/herbicide use will be the most significant determinants of native bee species richness and abundance and that surrounding landscape will have a much less significant impact (as in Winfree et al. 2008). We also predict that the only factor that will impact honey bee abundance is pesticide use, since honey bees are unlikely to be affected by surrounding landscape features and/or orchard size.

b. Bee community ➟ fruit set

Our goal is to determine if the abundance, species richness, or per-visit pollinator effectiveness of the local bee community has a detectable impact on fruit set in commercial apple orchards. If fruit set in apple orchards is correlated with abundance or species richness of the local pollinator community, it would provide clear evidence that apples are pollinator limited. If fruit set is uncorrelated with measures of abundance and species richness it would suggest that other factors (weather conditions, pests, drought) are responsible for poor fruit set in apple orchards. No previous studies have examine pollinator limitation in apple orchards. We will relate bee abundance, species richness, and per-visit effectiveness to our measures of fruit and seed set using multivariate analysis of variance, multivariate regression, and Spearman's rank order correlation coefficients (as in Montalvo & Ackerman 1986). We will use the following independent variables: total number of species (actually collected as well as estimated based on species accumulation curves), the abundance of bees (I_i; bees collected per minute), and the estimate of the overall community pollinator effectiveness (sum of T_i for each orchard). The primary dependent variables will be percentage fruit set in our experimental branches, number of seeds set/apple, and average number of seeds set per branch. Using this experimental design we will be able to detect whether fruit set is primarily determined by abundance of bees, species richness of bees (*per se*), or the product of abundance and effectiveness (sum T_i). We will also be able to examine if fruit set is more significantly correlated with native bee or honey bee abundance. This latter question will allow us quantify the relative importance of native bees *vis-a-vis* honey bees in apple pollination.

III. Impacts of our study on orchard management and the environment

Our project will provide important information on best practices for maximizing orchard pollination based on managing the abundance and diversity of native pollinators. First, our study will determine under what conditions native bees can provide effective pollination in commercial apple orchards. Orchard size, management, and the composition of the surrounding landscape may all be important predictors of the utility of the native bee fauna in orchard pollination. We will be able to develop guidelines for when orchard managers should avoid the extra cost of honey bee rentals and when they should use honey bees to assure good orchard pollination. Second, our study will quantify the relative contribution of native bees to apple pollination. This is important because the economic value of native pollinators has only rarely been determined and we currently have no quantitative assessment of the role of native bees in apple pollination. Third, our study will lead to specific guidelines and possibly modifications to current recommendations on pesticide and herbicide use in apple orchards. Recommendations will include specific suggestions on what pesticides to avoid and when to avoid pesticide applications. Overall, our project will develop recommendations for how growers can sustainably manage and preserve the biodiversity of pollinating native bees in an around apple orchards. Recommendations might include guidelines on optimal orchard size, alternative pollen and nectar sources in and around apple orchards, and soil management practices to insure sufficient nest-site conditions for ground-nesting bees. Cornell Cooperative Extension offices located throughout New York state (http://cce.cornell.edu) will facilitate grower contacts and dissemination of results. Our project will have a positive impact on the environment and human health by leading to reduced pesticide use and increased biodiversity in apple orchards.

IV. Hazardous procedures

Our field surveys and pollination experiments will be conducted in commercial apple orchards. One hazard posed by working in these conditions is pesticide exposure. All project participants will be required to take the "Worker Protection Standard Training" course offered by the Cornell College of Agriculture and Life Sciences office of Occupational and Environmental Health (http://oeh.cals.cornell.edu/wpstrain.html). The training is designed to protect agricultural workers (including Cornell students, staff, and faculty) from the risks of exposure to pesticide residues. Additional courses are available for more advanced training.

V. Timeline

<u>Annual schedule</u> (years 1-4):

February-March: field site selection; outreach and communication with growers and extension offices, including the Empire State Fruit and Vegetable Expo [http://www.nysaes.cornell.edu/hort/expo/] and Fruit Workers Meetings; preparation for field work

April-May: intensive field studies, including bee surveys, pollen deposition experiments, and fruit set experiments

June-September: specimen sorting, labeling, identification, and databasing; data collection for fruit set experiment; analysis of pollen deposition data (i.e., pollen counts)

October-January: data analysis; outreach and communication with growers and extension offices, including annual "Petal Fall" meetings, paper writing

<u>Annual outputs</u>:

Year 1: project set-up, data collection, preliminary data analyses
Year 2: data collection, data analysis, extension
Year 3: data collection, data analysis, extension, publication of results
Year 4: data collection, data analysis, extension, publication of results

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Key personnel

(1) **Bryan Danforth** (*Professor, Department of Entomology, Cornell University*) **–** B. Danforth will be the Project Director and will be responsible for coordinating activities of all participants. He will develop and coordinate the field experiments associated with this project, including choosing farm sites, developing survey methodologies, developing experimental protocols for determining pollen deposition rates and fruit set, and characterizing farms in terms of EIQ and surrounding landscape. He will work closely with a post-doc, a graduate student (Ms. Mia Park; see attached CV), a senior extension associate (Juliet Carroll; see attached CV and letter of support), and a number of undergraduate assistants. He will also take full responsibility for the safety of people associated with this project by ensuring that they have received full training in best practices for working in agricultural areas where pesticides are used. He will take lead responsibility for writing papers and reports stemming from this research.

(2) **Juliet Carroll** (*Senior Extension Associate, Cornell University*) **–** J. Carroll will be responsible for disseminating our results to growers via fact sheets, newsletters, e-mail reports, online publications, and personal contacts (grower meetings, training sessions, field demonstrations, visits, and telephone). In New York, opportunities for direct communication with growers include six petal fall / thinning meetings per year, winter fruit schools, and the annual Empire State Fruit and Vegetable Expo. Four extension newsletters will provide the opportunity to disseminate the information we learn about these pollinators in apple orchards directly to apple growers. In addition, she will make our results available via the Cornell Fruit Resources website, the NYS IPM Program website, and the regional fruit extension program websites through which we can publish this information.

(3) **Mia Park** (*Graduate Student, Cornell University*) **–** M. Park is a second-year graduate student working on the role of native bees in apple pollination. She is co-advised by John Losey and Bryan Danforth. She will play an important role in field site selection, development of sampling protocols, and field sampling. She will also take a lead role in characterizing per-visit pollinator effectiveness, fruit set, determining EIQ values, and analysis of surrounding landscape using GIS information. She will contribute to our extension activities by working closely with Jim Eve, Eve Farm Services, to deliver our results to growers in the Lake Ontario region.

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A. Professional Preparation

University of Maine	Botany	BS, 1978
University of Massachusetts	Plant Pathology	MS, 1981
Cornell University	Plant Pathology	PhD, 1995
Cornell University	Plant Pathology	Postdoctoral, 1999-2002

B. Appointments (Academic/Professional)

2003-present: Joint Faculty, Dept of Plant Pathology, Cornell University
2002-present: Senior Extension Associate II, NYS IPM Program, Cornell University
1996-1997: Outreach Consultant, The American Phytopathological Society
1981-1989: Extension Associate, Insect and Plant Disease Diagnostic Lab, Cornell University

C. Publications: 248 extension publications, 19 peer reviewed papers, 30 technical articles, 1 book.

(i) Five most relevant publications:

Agnello, A.M., Gardner, R., Helms, M., Smith, W., Landers, A.J., Rosenberger, D.A., Cox, K., Carroll, J.E., Robinson, T.L., Breth, D.I., Stiles, W., Curtis, P.D., Cheng, L., and Hoying, S.A. 2010. 2010 Pest Management Guidelines for Commercial Tree-Fruit Production. Cornell Cooperative Extension, Ithaca. 238 pp.

Carroll, J.E. 2010. TracApple version 2010 software. NYS IPM Program, Cornell University. http://nysipm.cornell.edu/trac/downloads/default.asp

Carroll, J.E. 2008. Promoting apple IPM implementation in Eastern New York orchards by expansion of the Northeast Weather Association. NYS IPM Program Project Reports 2007-2008, NYS IPM Pub 506: 37-47.

Carroll, J.E., Robinson, T.L., Agnello, A.M., Reissig, W.H., Rosenberger, D.A., Landers, A.J., Curtis, P.D., Cheng, L., Merwin, I.A., Lakso, A.N., Watkins, C.B., Nyrop, J.P., Straub, R.W., Breth, D.I., Hoying, S. A., Fargione, M.J., Iungerman, K.A. 2006. New York integrated fruit production protocol for apples. Food and Life Science Bulletin 158, NYSAES, Cornell University. 30 pp.

Carroll, J., Breth, D., Fargione, M., Iungerman, K., and Jordan, W. 2006. Eurepgap Certification for Apple Growers. Proc Great Lakes Fruit Expo, Grand Rapids, 2005, MI.

(ii) Five other publications:

Carroll, J., Pritts, M., and Heidenreich, C. (eds). 2010. Production Guide for Organic Blueberries. NYS IPM Publ. No. 225. Cornell Univ, Geneva, NY. 36 pp.

Carroll, J.E., Robinson, T., Burr, T. Hoying, S., and Cox, K. 2010. Evaluation of pruning techniques and bactericides to manage bacterial canker of sweet cherry. NY Fruit Quarterly 18(1):9-15

Pritts, M., Heidenreich, C., Gardner, R., Helms, M., Smith, W., Loeb, G., McDermott, L., Weber, C., McKay, S., Carroll, J.E., Cox, K., and Bellinder, R. 2010. 2010 Pest Management Guidelines for Berry Crops. Cornell Cooperative Extension, Ithaca. 112 pp.

Carroll, J.E., Fuchs, M. and Cox, K. 2009. Results of a New York Blueberry Survey. New York Fruit Quarterly. 17(4):19-22.

Loeb, G., Carroll, J. and Cha, D.H. 2008. Understanding tarnished plant bug colonization as a basis for developing an attraction-based management system for berry crops. NY Fruit Quarterly. 16:17-22.

D. Synergistic Activities

(i) *Extension education*: I teach extension educators, farmers and other stakeholders by giving 20+ presentations and workshops yearly on IPM of fruit crops, pest and disease forecast models, applied research projects, web-based resources, and organic production.

(ii) *Trac Software*: I create and provide online, nysipm.cornell.edu/trac/, easy-to-use Excel-based software for pesticide record-keeping, reporting, and farm traceability.

(iii) *Cornell Fruit Resources website:* I serve as coordinating editor for the website, www.fruit.cornell.edu/, which provides a portal to web-based fruit resources at Cornell University. I am Chair of the Web Committee within the Tree Fruit and Berry and the Grape Program Work Teams of Cornell Cooperative Extension.

E. Collaborators and Other Affiliations

(i) *Cornell Cooperative Extension*: Laura McDermott (Capital District Vegetable and Small Fruit Program), Hans Walter-Peterson (Finger Lakes Grape Program), Michael Fargione and Steve McKay (Hudson Valley Commercial Fruit Program), Tim Weigle, Jody Creasp-Gee, Andy Muza, and Kevin Martin (Lake Erie Regional Grape Program), Deborah Breth, Alison DeMarree, Craig Kalkhe, and Mario Miranda Sazo (Lake Ontario Commercial Fruit Program), Kevin Iungerman (Northeastern NY Commercial Fruit Program), Molly Shaw (South Central NY Agriculture Team), and Alice Wise and Dan Gilrein (Suffolk County Cornell Cooperative Extension).

(ii) *Cornell University Faculty*: Arthur Agnello, Harvey Reissig, Peter Jentsch, Greg Loeb, and Andrew Landers (Entomology), Kerik Cox, David Rosenberger, Marc Fuchs, Thomas Burr, Robert Seem, David Gadoury, and Wayne Wilcox (Plant Pathology), Terence Robinson, Steve Hoying, Marvin Pritts, Susan Brown, Courtney Weber, Alan Lakso, Tim Martinson, and Bruce Reisch (Horticulture), Art DeGaetano (Earth and Atmospheric Sciences), and Paul Curtis (Natural Resources).

(iv) *University Faculty – NE USA*: Lorraine Berkett (UVM), William Coli, Sonia Schloemann, and Jon Clements (U Mass)

BRYAN NICHOLAS DANFORTH
Professor

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A. Professional Preparation

Undergraduate institution: Duke University	Zoology	BS, 1983
Graduate institution: University of Kansas	Entomology	MS, 1987
Graduate institution: University of Kansas	Entomology	PhD, 1991
Postdoctoral institution: Cornell University	Entomology	1993-1995

B. Appointments (Academic/Professional)

2007-present: Professor, Cornell University, Ithaca, NY
2001-2007: Associate Professor, Cornell University, Ithaca, NY
1996-2001: Assistant Professor, Cornell University, Ithaca, NY
1995 (Spring): Lecturer, Cornell University, Ithaca, NY

C. Publications: 49 peer reviewed papers, 3 book chapters, 1 technical article, 1 book.

(i) Five most relevant publications:

Danforth, B.N., S.D. Sipes, J. Fang, & S.G. Brady (2006). The history of early bee diversification based on five genes plus morphology. Proc. Natl. Acad. Sci. (USA) 103(41): 15118-15123.

Danforth, B.N., J. Fang, & S.D. Sipes (2006). Analysis of family-level relationships in bees (Hymenoptera: Apiformes) using 28S and two previously unexplored nuclear genes: CAD and RNA polymerase II. Mol. Phylogenet. Evol. 39 (2): 358-372.

Brady, S.G., S.D. Sipes, A. Pearson, **B.N. Danforth** (2006). Recent and simultaneous origins of eusociality in halictid bees. Proc. Royal Soc. London, Series B (Biological Sciences) 273:1643-1649.

Brady, S.G. & **B.N. Danforth** (2004). Recent intron gain in elongation factor-1α (EF-1α) of colletid bees (Hymenoptera: Colletidae). Mol. Biol. Evol. 21(4):691-696.

Danforth, B.N., S. Ji, & L.J. Ballard (2003). Gene flow and population structure in an oligolectic desert bee, *Macrotera* (*Macroteropsis*) *portalis* (Hymenoptera: Andrenidae). J. Kansas Entomological Society 76(2): 221-235.

(ii) Five other publications:

B.N. Danforth (2007). Bees - a primer. Current Biology 17(5): R156-R161.

Poinar, G.O., Jr. & **B.N. Danforth** (2006). A fossil bee from Early Cretaceous Burmese amber. Science 314: 614.

Schwarz, M.P., M.H. Richards & **B.N. Danforth** (2007) Changing paradigms in insect social evolution: insights from halictine and allodapine bees. Annual Review of Entomology 52:127-150.

Wcislo, W.T. & **B.N. Danforth** (1997). Secondarily solitary: the evolutionary loss of social behavior. Trends Ecol. Evol. 12:468-474.

Michener, C.D., R.J. McGinley & **B.N. Danforth** (1994). *The Bee Genera of North and Central America (Hymenoptera: Apoidea)*. Smithsonian Institution Press, Washington, DC. vii+209pp.

D. Synergistic Activities

(i) *Undergraduate and graduate education*: I teach three courses at Cornell University: Entom. 201 (Alien Empire: Bizarre Biology of Bugs), Entom. 331 (Insect Phylogeny and Evolution), and Entom. 322 (Insect Comparative Morphology). These classes attract approximately 100, 20, and 15 students, respectively. Alien Empire: Bizarre Biology of Bugs has the broadest impact by introducing a broad cross-section of Cornell students to the bizarre and interesting lives of insects.

(ii) *The Bee Course* (http//research.amnh.org/invertzoo/beecourse): I participate annually as an instructor for "The Bee Course," a ten day, intensive introduction to the systematics, biology, and conservation of native bees. The course is organized by Dr. Jerome G. Rozen, Jr. (American Museum of Natural History) and has been offered for the past seven years (1999-2006) in the Southwestern Research Station, Portal, AZ. We attract approximately 20 students per year from diverse backgrounds and from around the world. The course will be offered again in August, 2007.

(iii) *Bee Phylogeny website* (http://www.entomology.cornell.edu/BeePhylogeny/). This website provides information on bee phylogeny, fossil record, and biogeography as well as detailed information on genes and PCR primers that we have developed for sequencing single-copy nuclear genes in bees. Maps of genes, lists of primers, sequencing protocols, related literature, and DNA sequence alignments can be downloaded.

E. Collaborators and Other Affiliations

Collaborators and co-editors – S. Brady (Smithsonian Institution), T. Griswold (USDA Bee Biology Lab, Logan, Utah), C.-P. Lin (University of Missouri), R. Minckley (University of Rochester), L. Packer (York University, Canada), M. Richards (Brock University, Canada), M. Schwarz (Flinders University, Australia), S. Sipes (Southern Illinois University), E. Almeida (Universidade Federal do Paraná, Brazil).

Graduate or Postdoctoral Advisors – Charles D. Michener (University of Kansas), George C. Eickwort (Cornell University; deceased).

Thesis Advisor or Post-graduate Sponsor – Margarita Lopez-Uribe (PhD), Jessica Litman (PhD), Sophie Cardinal (PhD), Eduardo Almeida (PhD), John S. Ascher (PhD), Karl N. Magnacca (PhD), Chung-Ping Lin (PhD), Sedonia Sipes (post-doc), Sean Brady (post-doc).

MIA G. PARK
PhD Student in the Department of Entomology

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A. Professional Preparation

University of California, Davis	Environmental Sciences	B.S., 1999
Cornell University	Natural Resources	M.S., 2006

B. Appointments

2009-present Teaching assistant for IPM for Practitioners, Phylogeny and Evolution, Cornell U.
2008-2009 Graduate Research Fellow, Department of Entomology, Cornell U.
2007-2008 Intern and consultant for various non-profit, conservation organizations including Conservation International, Arlington, VA, and EcoAgriculture Partners, Ithaca, NY
2006-2007 Curatorial Assistant, California Academy of Sciences, San Francisco, NY
2005-2006 Teaching assistant for introductory biology courses, Cornell U.
2002-2005 Graduate Research Assistant, Department of Natural Resources, Cornell U.

C. Publications

Park, MG, M. Orr and B. Danforth. 2010. The Role of Native Bees in Apple Pollination. New York Fruit Quarterly. Spring (accepted, *in press*).

Park, M.G. and B. Blossey. 2008. Influence of stem traits and herbivory on invasive success of *Phragmites australis* (Poaceae). American Journal of Botany 95(12): 1557-1568.

Park, M.G. and B. Blossey. Influence of six wetland plant species on decomposition dynamics and invertebrate diversity of a NY freshwater marsh. NABS (*in progress*).

D. Collaborators and Other Affiliations

(i) Collaborators:
Bryan Danforth, Cornell University; John Losey, Cornell University; Art Agnello, Cornell Experimental Field Station; Jim Eve, Eve Consulting Service.

(ii) Affiliations:
Entomological Society of America
Xerces Society
Society of Conservation Biologists
Ecological Society of America

FACILITIES AND OTHER RESOURCES

Departmental resources: The Department of Entomology at Cornell provides secretarial assistance, computer consulting and networking assistance, phones and ethernet connections.

Laboratory facilities: Danforth's laboratory is fully equipped for the work associated with this project, including pollinator surveys and pollination biology. For pollinator surveys and bee identifications we have three Wild M3Z stereomicroscopes, and two Zeiss Stemi SV11 stereomicroscopes. The two Zeiss scopes are equipped with camera lucidas for preparing drawings. One Zeiss SV11 is equipped with a phototube and a Sony DSC digital still camera. For pollination biology we have we a Wild M20 phase-contrast compound microscope for pollen identification and quantification.

Collection and library facilities: The Cornell University Insect Collection is located one floor below my laboratory and has a world-wide collection of pinned insects that will serve as a resource for bee identifications. Currently the collection houses over 6 million specimens identified to 200,000 species. Our bee collection consists of 390 Cornell drawers including an estimated 150,000 to 270,000 bee specimens identified to species. The majority of our bee collection represents eastern North American bee species. This is a tremendously valuable resource for identifying bee species collected in our surveys. Comstock Hall houses the Comstock Memorial Library, an outstanding collection of entomological literature.

Computer facilities: My laboratory is equipped with three MacIntosh computers (G5, G4, and iMac) and one Dell Optiplex 960 desktop computer. The Dell Optiplex 960 computer has a scanner, drawing tablet, and drawing software (Adobe Illustrator, Adobe Photoshop, and Corel Draw) for preparing digital art work and editing digital images. For GIS analysis, we have an annual subscription for the ArcGIS v. 9.3 software and databases for New York State are available from Cornell University Geospatial Information Repository (CUGIR; http://cugir.mannlib.cornell.edu/), an online repository in the National Spatial Data Clearinghouse program. In addition, The Cornell University Insect Collection houses two additional Dell Optiplex 960 desktop computers for database management and data analysis.

Office space: Personnel associated with this grant will be provided office space adjacent to my laboratory.

EQUIPMENT

MAJOR EQUIPMENT:

Cornell University: No major equipment is needed for this project.

CURRENT & PENDING SUPPORT

Name: Bryan N. Danforth

Instructions:
Who completes this template: Each project director/principal investigator (PD/PI) and other senior personnel that the Request for Applications (RFA) specifies
How this template is completed:

- Record information for active and pending projects, including this proposal.
- All current efforts to which PD/PI(s) and other senior personnel have committed a portion of their time must be listed, whether or not salary for the person involved is included in the budgets of the various projects.
- Provide analogous information for all proposed work which is being considered by, or which will be submitted in the near future to, other possible sponsors, including other USDA programs.
- For concurrent projects, the percent of time committed must not exceed 100%..

Note: Concurrent submission of a proposal to other organizations will not prejudice its review by CSREES.

NAME (List/PD #1 first)	SUPPORTING AGENCY AND AGENCY ACTIVE AWARD/PENDING PROPOSAL NUMBER	TOTAL $ AMOUNT	EFFECTIVE AND EXPIRATION DATES	% OF TIME COMMITTED	TITLE OF PROJECT
Danforth, B.N.	Active: USDA Hatch grant	$57,900	1 Oct. 2008- 31 Sept. 2011	10%	Diversity and pollination biology of native bees in apple orchards in New York.
Danforth, B.N.	Active: National Science Foundation, Systematic Biology, DDIG grant	$11,992	1 July 2008 – 30 June 2010	10%	Dissertation Research: Evolution of Cleptoparasitism in apid bees (Hymenoptera: Apidae)
Danforth, B.N.	Active: National Science Foundation, Systematic Biology REVSYS (*in collaboration with T. Griswold, USDA, Logan, UT*)	$370,000	1 Feb. 2008 – 31 Jan. 2012	20%	REVSYS: Phylogeny and systematics of megachilid bees
Danforth, B.N	Active: National Science Foundation, Systematic Biology	$393,736	1 July 2008 – 30 June 2011	20%	Phylogeny of Apidae (Hymenoptera) with an emphasis on the evolution and antiquity of eusociality
. Danforth, B.N.	Pending: USDA-AFRI, Plant Health and Production and Plant Products: b. Pest and Beneficial Insects in Plant Systems	$495,925	1 Jan. 2011 – 31 Dec. 2015	20%	Importance of native bees in Northeastern apple production and the factors that maximize their pollination services

This file MUST be converted to PDF prior to attachment in the electronic application package.

CONFLICTS OF INTEREST

Name: **Bryan N. Danforth**, Cornell University

Name	Co-Author	Collaborator	Advisees/ Advisors	Other
Almeida, Eduardo			x	
Ascher, John			x	
Brady, Sean	x	x		
Cardinal, Sophie			x	
Eardley, Connal	x	x		
Griswold, Terry	x	x		
Kawakita, Atsushi		x		
Larkin, Leah	x	x		
Lin, Chung-Ping			x	
Litman, Jessica			x	
Lopez-Uribe, Margarita				x
Magnacca, Karl			x	
McGinley, Ronald			x	
Michener, Charles			x	
Michez, Denis	x			
Minckley, Robert		x		
Mueller, Andreas		x		
Packer, Lawrence	x			
Patiny, Sebastien	x			
Poinar, George	x			
Praz, Christophe		x		
Sipes, Sedonia	x	x		
Walker, Kenneth	x			

Name: **Juliet Carroll**, Cornell University

Name	Co-Author	Collaborator	Advisees/ Advisors	Other
Abawi, George S.	x			x
Agnello, Arthur M.	x	x		
Albers, Carl			x	
Bergstrom, Gary C.				x
Bornt, Charles			x	
Breth, Deborah I.	x	x		
Burr, Thomas J.	x	x		
Cha, Dong	x			
Cheng, Lailiang	x	x		
Cheng, Peichen	x			
Cox, Kerik	x	x		
Cramer, Craig	x	x		

Curtis, Paul D.	x	x		
Danforth, Bryan			x	
DeGaetano, Art			x	
Fargione, Mike	x	x		
Fuchs, Marc	x	x		
Gadoury, David M.	x	x		
Gibbons, John	x	x		
Grant, Jennifer	x	x		
Gugino, Beth	x			
Heidenreich, M. Catherine	x	x		
Hoepting, Christine			x	
Hoying, Steven	x	x		
Iungerman, Kevin A.	x	x		
Jentsch, Peter			x	
Lamb, Elizabeth			x	
Landers, Andrew J.	x			
Loeb, Greg	x	x		
Martinson, Timothy			x	
Park, Mia			x	
Petzoldt, Curtis H.	x	x		
Pritts, Marvin	x	x		
Reissig, W. Harvey	x	x		
Robinson, Terence L.	x	x		
Rosenberger, David A.	x	x		
Rutz, Donald			x	
Seaman, Abby			x	
Seem, Robert C.	x	x		
Tattar, Terry				x
Ten Eyck, Cheryl	x	x		
Ullrich, Maire			x	
Waldron, Keith			x	
Walter-Peterson, Hans			x	
Weigle, Timothy	x	x		
Wilcox, Wayne F.	x	x	x	

Name: **Mia Park**, Cornell University

Name	**Co-Author**	**Collaborator**	**Advisees/ Advisors**	**Other**
Blossey, Bernd				x
Losey, John				x

AFRI PROJECT TYPE

Instructions:
Who completes this template: Each project director (PD) applying to the Agriculture and Food Research Initiative (AFRI) Request for Applications (RFA)
How this template is completed:

- Check one Project Type Box and one Grant Type Box.
- For FASE Grants, select an appropriate sub-category.

Project Type

- ☒ Research
- ☐ Education
- ☐ Extension
- ☐ Integrated

Grant Type

- ☒ Standard Grant
- ☐ Coordinated Agricultural Project (CAP) Grant
- ☐ Planning / Coordination Grant
- ☐ Conference Grant
- ☐ Food and Agriculture Science Enhancement (FASE) Grant
  - ☐ New Investigator
  - ☐ Strengthening
    - ☐ Sabbatical
    - ☐ Equipment
    - ☐ Seed
    - ☐ Strengthening Standard
    - ☐ Strengthening CAP

Arthur M. Agnello
Professor, Extension Fruit Entomology
Dept. of Entomology
630 W. North St.
N.Y.S. Agric. Expt. Station
Geneva, NY 14456-1371
Telephone: 315-787-2341
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email: ama4@cornell.edu

25 March 2010

Dr. Bryan Danforth
Dept. of Entomology
3119 Comstock Hall
Cornell University
Ithaca, NY 14853-0901

Dear Bryan:

This letter documents my support of your efforts to characterize and expand the role of native bees in apple pollination in New York State, specifically within the context of your proposal to the USDA AFRI Grants Program 2010. Having cooperated with you and your program during some of the baseline data collection studies last year, I recognize the importance and potential value of our region's diverse collection of bee species, and I am pleased to be able to work with you in promoting information on their conservation and use to our tree fruit industry. I would be willing to help disseminate your results using whatever delivery methods and opportunities are available through our Fruit Extension Program activities; these would include special bulletins or Fact Sheets, weekly seasonal newsletters such as "Scaffolds" (http://www.nysaes.cornell.edu/ent/scaffolds/), county and regional extension service letters, online publications such as the NY Fruit Quarterly (http://www.nyshs.org/fq.php), and at grower meetings such as The Empire State Fruit & Vegetable Expo in Syracuse, County and Regional Fruit Team winter meetings in the Lake Ontario, Hudson Valley, and Lake Champlain regions, plus more informal field meetings such as during the petal fall period. Additionally, recommendations for implementing these tactics would be appropriate for inclusion in the NY Pest Management Guidelines for Commercial Tree Fruit Production (http://ipmguidelines.org/treefruits/), ensuring that the results identifying the most effective and practical use of this information to manage this resource will be incorporated into the printed and online reference publication used most frequently by the region's tree fruit growers.

Sincerely,

Arthur M. Agnello
Professor and
Extension Entomologist

Cornell University
New York State
Integrated Pest Management Program

Juliet E. Carroll
Fruit IPM Coordinator

630 West North Street
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www.nysipm.cornell.edu

March 30, 2010

Bryan N. Danforth, Professor
Department of Entomology
3119 Comstock Hall
Cornell University
Ithaca, NY 14853-0901

Dear Bryan,

I am writing to confirm my support for your project on native bee pollinators in apple orchards that you are submitting to USDA AFRI. I am willing to help you disseminate your results via a variety of extension methods, including fact sheets, newsletters, e-mail reports, online publications, and personal contacts (grower meetings, training sessions, field demonstrations, visits, and telephone).

In New York, there are six petal fall / thinning meetings each year for apple growers in NE NY, the Hudson Valley, and the Lake Ontario plains. There are winter fruit schools and the Empire State Fruit and Vegetable Expo. Four extension newsletters will provide the opportunity to disseminate the information you learn about these pollinators in apple orchards directly to apple growers. In addition, we have the Cornell Fruit Resources website, the NYS IPM Program website, and the regional fruit extension program websites through which we can publish this information.

Pollination is paramount to apple production and fruit quality. I know growers will be keenly interested in the information you generate through this research. I am looking forward to learning more about native pollinators and extending your research information at grower meetings and through written media as part of your project.

Sincerely,

Juliet E. Carroll
Senior Extension Associate II

April 8, 2010

Bryan N. Danforth, Professor
Mia Park, PhD Student
Department of Entomology
3119 Comstock Hall
Cornell University
Ithaca, NY 14853-0901

Dear Bryan and Mia,

This is a letter in support of your application to the USDA-AFRI program on Pest and Beneficial Insects in Plant Systems program. I am a private consultant working with apple growers in New York State. I am also engaged in other tree fruit crops as well as small fruits.

I have substantial contacts with growers across the state, especially in the area south of Lake Ontario, where you propose to conduct your research. I believe your project has the potential to significantly impact the management practices of Northeast apple growers by providing new information on the role of native bees in apple pollination.

Many of the growers who participate in our service program have a strong interest in preserving and maintaining native bee diversity in and around their farms. However, information is currently lacking on how best to do this. Your project will fill an important gap in this area. I am very willing to help you contact orchard managers, choose orchards for your studies, and disseminate your results among the growers with whom I work.

Sincerely,

James Eve, Jr.

Eve Farm Service, LLC
8791 Eelpot Road
Naples, NY 14512

Cell: 585.721.2682

RUTGERS
School of Environmental
and Biological Sciences

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www.winfreelab.rutgers.edu

27 March 2010

To Whom in May Concern:

I have read through Bryan Danforth's USDA AFRI proposal to study native, wild bees as pollinators of apple crops in New York State, and am enthusiastic about the significant contribution that this research will make to our general understanding of native insects as crop pollinators. The proposed work does not overlap with my ongoing, AFRI-funded research, since Dr. Danforth's project focuses on apple, which is not a system I intend to study in the foreseeable future. Rather, the knowledge gained by Dr. Danforth's proposed work would be complementary to my research, and would lead to a more complete understanding of the role of native crop pollinators in the eastern USA.

Sincerely,

RWinfree

Rachael Winfree
Assistant Professor
Department of Entomology