Guide to Integrated Crop Pollination





Integrated crop pollination (ICP) is the use of managed pollinator species in combination with farm management practices that support, augment, and protect pollinator populations to provide reliable and economical pollination of crops. These pollination strategies are the focus of the Integrated Crop Pollination Project – a multi-year Coordinated Agricultural Project funded by the USDA-NIFA Specialty Crop Research Initiative. Members of the project team are investigating the performance, economics, and farmer perceptions of different pollination strategies in various fruit, nut, and vegetable crops.

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Honey bee hives in a Michigan tart cherry orchard. Photo by Katharina Ullmann, The Xerces Society.

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Introduction

Many of the fruits, nuts, vegetables and herb crops that provide us with important nutrients depend on animal pollination to produce marketable and profitable yields. These pollinators move pollen from the male parts of crop flowers to the female parts of crop flowers, pollinating crop flowers. Fertilized crop flowers create seeds that are sometimes surrounded by a fleshy, edible fruit.

Growers of pollinator-dependant crops know that pollination enhances crop yield. However, efficient pollination can also improve crop quality. For example, pollination:

- Improves almond nutritional value;
- Increases canola oil content;
- · Increases mandarin orange sugar content;
- Increases size and fruit set in blueberries, apples, and pears;
- · Improves strawberry fruit shape and shelf life;
- Ensures marketable fruit shape for many crops, including apples, raspberries, blackberries, and summer squash.

Most growers actively manage nutrients, water, pests, and diseases to achieve high yields, but without good pollination, the investment in land, plants, and crop protection can be wasted. This guide, focused on pollinator-dependent specialty crops, provides an overview of a new approach to optimizing pollination in agriculture called Integrated Crop Pollination (ICP).

Integrated crop pollination is the use of managed pollinator species in combination with farm management practices that support, augment, and protect pollinator populations to provide reliable and economical pollination of crops.





Blueberries, like many specialty crops grown in the United States, depend on pollinators to set fruit. On the left is a blueberry branch that was pollinated and on the right, one that lacked pollination. Photo by Julianna Wilson, Michigan State University.

Depending on the farm context and current levels of crop pollination, increasing the stocking density of managed bees or augmenting honey bees with alternative managed bee or wild bee species may increase yields. In addition, implementing habitat enhancements, pesticide stewardship practices, or horticultural practices that feed or protect wild and managed bees can ensure that crop pollinators stay healthy and provide a return on growers' investments.

Growers rely on managed and wild pollinators to ensure crop pollination. However, in recent years, both managed and wild bees have faced declines that threaten growers' access to consistent, reliable pollination. For example, since 2006 between 30% and 44 % of U.S. honey bee colonies were lost each year. These losses were the result of pests, diseases, poor nutrition, exposure to pesticides and other factors that stress honey bee health. In turn, honey bee rental prices have increased because beekeeping has become more expensive and demand for colonies continues to increase.

There is also evidence that some wild bee species are declining. Loss of natural habitat, pesticide exposure, and diseases threaten their survival. Habitat areas close to farms have the potential to provide these bees with safe nesting sites and pollen- and nectar rich flowers to help mitigate these threats.

Why integrate pollination strategies?

Growers can make use of a number of different types of bees to pollinate crops: honey bees, alternative managed bees such as mason bees and bumble bees, and hundreds of species of wild bees. Some other insects (e.g., flies) are also important for crop pollination. However, we focus on bees in this document because they are the most effective pollinators for many crops.

Diversifying the bees used to pollinate crops can help ensure reliable, consistent pollination. If one bee species is not active, another may be able to visit flowers. Using a combination of bee species also helps ensure that all flowers are pollinated using the strengths of different pollinators. For example, when both honey bees and wild bees are present, strawberry flowers are pollinated more evenly because honey bees pollinate the center of the strawberry flower, while wild bees pollinate the perimeter. The result is a more marketable fruit with a more stable shelf life.



Researchers found that, in Caliornia almonds, wild bees and blue orchard bees make honey bees better pollinators. Photo by Derek Artz, USDA-ARS.

Because different bees prefer different weather conditions, having a combination of bee species can ensure that flowers get pollinated even when optimal pollination days are limited. For example, a study in almond found that in windy weather, honey bees stay in the bottom interior of the canopy, while wild pollinators will continue to visit flowers throughout the tree. In addition, researchers studying highbush blueberries found that honey bees were more abundant on blueberry during good weather conditions, while bumble bees were more abundant during poor weather.

Finally, multiple bee species working together can lead to synergistic benefits where honey bees become better pollinators. For example, a study in almond orchards found that wild bees and blue orchard bees, a type of mason bee, make honey bees move more frequently between varieties. This leads to greater yields than when honey bees are in the orchard alone and only move along, rather than between, the rows. Similarly, researchers found that when wild bees are present, honey bees move more between male and female rows in fields growing hybrid sunflower seed, leading to a fivefold increase in seed set.

Grower spotlight: Cornerstone Ag Enterprises, LLC (Michigan blueberries)

Larry Bodtke is a second generation blueberry farmer whose family farm, Cornerstone Ag Enterprises, LLC, grows almost 1,000 acres of blueberry in southwest Michigan. Like many growers, getting consistent, reliable pollination is a top priority for him. "When I think of managing blueberries, pollination is right up there near the top [of the list] because all the other things that we do [won't matter] if the berry doesn't get pollinated," says Bodtke. "We get better yields and better sized berries if we get good pollination."

In order to support the pollinators he depends on, Mr. Bodtke aims to minimize the impact of crop pest and disease management on bees and maintain wildflowers and woodlots that provide food and nesting sites for bees, "Anything that we can do to help increase those populations, that can help us get better pollination, we're certainly going to look at. One of the shorter term things that we do [to protect bees] is try to alter our spray schedule. Obviously, we don't use any chemicals that are harmful



Larry Bodtke, a blueberry grower in Michigan, uses practics associated with integrated crop pollination. Photo by Emily May, The Xerces Society.

to the bees while they're out working in the fields. From a long-term perspective, we try and keep some woods around our fields or at least tree-lines. Those are good for several different reasons – it's good for nesting [bees] and it also helps keep the wind down a little bit, and that's good for bee flight and cold winter winds."

In addition to altering spray schedules and maintaining natural habitat around their fields, the Bodtkes have planted 5 acres of perennial wildflower meadows next to their blueberry fields. These wildflower mixes consist of 15-20 species of native, perennial wildflowers and 3 species of native grasses. Researchers from Michigan State University documented that yield increased by 10-15% at the edge of blueberry fields next to these plantings. However, the full benefits are typically not reached until four years after planting.

Who are the key crop pollinators and what do they need?

Honey bees, alternative managed bees, and wild bees are all pollinators of specialty crops. In the next three sections, we provide more details about the natural history of these improtant pollinators and how to support them.

HONEY BEES

Honey bees (*Apis mellifera*) are managed across North America for the honey and pollination services they provide. This species of honey bee has a natural distribution in Africa, the Middle East, and Europe and is composed of nearly 30 subspecies, or races, all with unique behavioral attributes. For thousands of years, people have valued honey bees largely for the honey they produce. In fact, this is why Europeans brought western honey bees to the United States hundreds of years ago.

Honey bees, of course, are important for another reason beyond producing honey, they pollinate hundreds of species of plants. Honey bees, like other bees, collect pollen in order to feed young bees. While most other bees rear their young on pollen balls moistened with nectar, the honey bee larval diet comes from brood food that adult worker bees produce from special glands. To produce this brood food, adult bees must consume copious amounts of pollen.

NATURAL HISTORY OF HONEY BEES

The honey bee colony is a collection of adult and immature honey bees functioning together as a single unit. Honey bee colonies live in nests or hives, the latter typically referring to the structure in which managed colonies live. There are three types of adult honey bees that compose the colony: the queen, thousands of female workers, and a few hundred male bees called drones. Usually, a colony has one queen. She lays all of the eggs in the hive, and her presence maintains stability within the hive. Worker honey bees are female honey bees and they perform most of the tasks in the hive. These tasks include tending the queen, feeding and caring for immature bees, constructing wax combs, foraging for food, and guarding the hive. Worker bees defend their colonies by stinging and they collect food for the colony by visiting many flowers. The typical honey bees cannot sting, and exist only to mate with young queens.

Honey bees undergo complete metamorphosis, meaning that they pass through egg, larval, pupal, and adult stages of development. These immature stages are called "brood". Brood create the colony's demand for pollen, leading the worker force to forage for pollen. Colony size grows and shrinks seasonally depending on resource (pollen and nectar) availability. In a typical year, colonies come out of winter somewhat small, grow significantly through spring as copious amounts of nectar and pollen become available, stabilize in size in early summer, and begin a slow decrease in size from midsummer through fall. Colonies store honey in their nests in order to have the energy resources needed to survive winter, when floral resources are scarce and weather conditions are too poor to leave the hive.

Worker honey bees leave their nests to forage for one of four substances. First, they collect nectar from flower nectaries (glands located at the base of a flower that secrete nectar) and extrafloral nectaries (nectaries located on other parts of the plant). They convert this nectar to honey. Honey is bee fuel; the sugar in honey helps power bee activity. Honey bees also collect water from multiple sources (ponds, rivers, lakes, leaky faucets, drip lines, etc.) to use in their hive for cooling purposes. The third group of substances that honey bees collect includes saps and resins from plants that they place in their hives for weatherproofing and antimicrobial purposes. Beekeepers call this group of substances "propolis". Fourth and finally, honey bees collect pollen from plants. They moisten the pollen with nectar, pack it into pollen baskets on their wide hind legs, and store it in their colonies as bee bread. Bee bread provides the protein, vitamin and mineral resources bees need. As a result of the honey bees' insatiable appetite for pollen, plants get pollinated and countless ecosystems and agriculture systems benefit.

HONEY BEES AS CROP POLLINATORS

Honey bees, like other bees, are built for pollen gathering. They are covered in branched hairs that build up an electrostatic charge as they fly. This charge causes pollen from plant anthers, the male parts of a plant, to jump onto the bees' bodies when they land at the center of the flower. Honey bees have modified legs with which they rake pollen from their bodies and pack it onto their hind legs in their pollen basket, which is composed of two rows of stiff hairs that hold pollen onto their hind legs.



A worker honey bee with a pollen pellet on its hind leg. Photograph by Michael Bentley.

Honey bees are effective crop pollinators for multiple reasons. First, honey bees collect pollen and/ or nectar from a wide variety of flowering plant species rather than from a select few, which means they willingly visit many different types of crop flowers. This trait makes honey bees ideal pollinators for a variety of crops. Generally speaking, honey bee colonies need pollen from a variety of sources because no one pollen contains all of the protein, minerals, and nutrients the bees need. Some pollens, for example, are higher in protein content than others.

Bee bread stored in wax combs. Worker honey bees collect pollen from flowers, moisten it with nectar, pack it on their hind legs, and bring it back to their hives for use. In the hive, they pack the pollen into wax cells, where the pollen is processed further into bee bread. The presence of honey bee larvae in the nest creates the colony's demand for pollen. Photograph by Michael Bentley.



Second, their colonies can contain large numbers of bees, up to 40,000 individuals. This is important since honey bees are not always the most efficient pollinator on a bee-tobee basis when compared to other bees. Bumble bees, for example, are more efficient pollinators of blueberries than are honey bees when looking at single bee contributions to the pollination of a given flower. However, what honey bees lack in efficiency, they compensate for in numbers. No other managed bee colonies are as large as those of honey bees.

Third, honey bee hives are manageable and perennial. This means that beekeepers can manage their colonies to address health and productivity issues, move their hives from crop to crop throughout the year, and expect their colonies to survive until the following year when they can be used again.

And lastly, honey bees have a large foraging range compared to those of other bees. Forager honey bees can fly 3 – 5 miles (4.8 - 8 km) from the hive in search of nectar and pollen. This translates to an area of 28 - 79 mi² (73 - 205 km²) around a single hive that can be pollinated by honey bees. Despite this large foraging range, honey bees forage best and most energetically around the nest.

Many beekeepers keep honey bee colonies for the purpose of generating income by providing crop pollination services. In this case, the beekeeper's hives are rented by a grower for a cost/ hive fee. Hive rental fees range from \$40 – 90 for many crops, but can be as high as \$175 – 200 for almonds in California. The hives placed on the crop may have different configurations and usually are kept on pallets when part of commercial beekeeping operations. The average commercial beekeeper who uses bees to provide pollination services places hives on 4 to 5 different crops per year, moving them by truck from farm to farm.

There are challenges with using honey bees to provide crop pollination services. First, growers have to pay a fee for this service. This is a cost that does not exist for growers relying on wild bees for pollination purposes. Furthermore, without a good understanding of colony growth, biology, pollination ecology, etc., it can be difficult for growers to know if honey bee colonies are performing the service for which they are paying.

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Common hive configuration. The typical honey bee hive used for pollination purposes is composed of one to three boxes or "supers". Most hives moved to crops for pollination purposes are composed of a single deep box or two boxes. Photograph by Jamie Ellis, University of Florida.



Managed honey bee hives placed in an almond grove in California. Commercial beekeepers typically keep four to six hives on a single pallet to make moving the hives more efficient. The hives in this picture all are composed of two deep supers. Each stack of supers represents a single hive inhabited by a single colony. There are four hives per pallet in this picture. Photograph by Liana Teigen, University of Florida.

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In addition, managed honey bee colonies have been experiencing high colony loss rates since about 2006. Beekeepers across the U.S. report gross loss rates that exceed, on average, 30% yearly. Managed honey bees have a suite of problems that beekeepers have to manage actively. These high loss rates have caused honey bee rental fees to increase, and many growers have considered using alternative pollinators.

Finally, honey bees also tend not to forage well in inclement weather. This includes cooler temperatures, early mornings and late evenings, during light rain, and under windy conditions. Other bee species forage in these conditions better than honey bees. Another drawback to honey bees is that they prefer flowers containing high quality pollen and/or nectar resources. Many crops needing bee pollination, e.g., blueberries, cranberries, and onion seed, produce low or no nectar or low quality pollen. Thus, honey bees may fly over the target crop to forage on a better quality resource located in the surrounding landscape.

USING MANAGED HONEY BEES TO PROVIDE POLLINATION SERVICES

All honey bees pollinate, but some colonies are better-suited to provide these services than others. Growers renting honey bee hives should ensure the following colony conditions are met in order to achieve maximum pollination efficiency.

• First, the top 6-10 frames in the hive should have enough worker bees that their bodies form a continuous layer at the top of those frame. This demonstrates that the colony has sufficient worker bee strength to provide pollination services.

• Second, the colony should have a laying queen present in the hive. It should not be queenless. Queens lay the eggs from which the larvae emerge and it is larval consumption of brood food derived from pollen that causes worker bees to forage for pollen.

• Consistent with the second point, the hive should contain enough brood (eggs, larvae, and pupae) to fill at least 4, and ideally 6 or more frames. A lot of this brood should be larvae. Larvae create the greatest demand for pollen, leading adult worker bees to forage for it.

• There should be no uncontrolled diseases or pests in the hive. Sick or compromised colonies do not pollinate as well as stronger ones.

Other points to consider when using honey bees to provide pollination services:

• Honey bees forage best around their hives. Thus, the current guidelines on optimum placement of single hives within a field is one every 500 ft (152 m) throughout the target field.

• Honey bee hives should be placed adjacent to or in the target crop when the crop is in about 10% bloom. Placing honey bee colonies adjacent to the crop before it is in bloom could cause the honey bees to find an alternative source of forage and continue to use that forage, even when the crop blooms.

• Honey bee hives should be kept out of low-lying areas that are prone to flooding, breezy, or damp.

• Where possible, hives should be protected from strong winds by placing them behind walls, hedgerows, hay bales, etc.

• Honey bee hives should be located away from areas frequented by farm workers or animals.

• If a water source is not provided or available, the honey bees may collect water from irrigation equipment, swimming pools, etc. It is advisable to have a source of protected (e.g., pesticide-free) water near the hives.

• It is recommended that beekeepers and growers have a written contract or pollination agreement that dictates the terms of the relationship including stocking rate, location of hive placements, time of hive arrival and removal, and any concerns related to pesticide use. This sample pollination agreement from University of Florida is a good starting point.

• Pesticide impacts on honey bees is of significant concern to beekeepers. See "<u>Minimizing</u> <u>honey bee exposure to pesticides</u>" from University of Florida for recommendations on mitigating possible impacts of pesticides to bees.

• Check with your university extension agent or consult the book "Crop Pollination by Bees" (Delaplane & Mayer, 2000, see additional references at the end of this document) to determine the recommended honey bee hive stocking densities (number of hives per acre) for your crop. This book is an excellent reference for growers and should be consulted when questions on stocking densities arise.

• It is common for beekeepers to manage honey bee hives that are actively providing pollination services for growers. This includes feeding and treating colonies, practicing swarm control, etc. Growers should talk to beekeepers about the management practices the beekeeper plans for the hives while they are on site to determine how such practices may impact colony pollination efficacy.

Honey bees are managed to pollinate many crops, including highbush blueberry. Photo by Emily May, The Xerces Society.



ALTERNATIVE MANAGED BEES

A small number of other of species bees are commercially managed to provide pollination services. These are used when managed honey bees or wild bees are not available or when managed honey bees are not the most efficient pollinators available. For example, some fruit and nut crops bloom early in the spring before honey bees have had time to build up their colony brood strength after winter. As a result, the supply of honey bees may not be as great as the demand. In addition, honey bees may not be able to fly in cool and wet spring weather.



Managed bumble bees can be used to pollinate some specialty crops. Photo by Mary Bammer, University of Florida.

In these instances, managed bumble bees (*Bombus* species) and orchard mason bees (*Osmia* species) may be employed as pollinators. These alternative bees are naturally adapted to forage in cool weather and can be managed to be active when crop bloom begins.

NATURAL HISTORY OF ALTERNATIVE MANAGED BEES

Because these bees are markedly different from honey bees, it is important to understand their social structure, life cycles, and resource and management needs.

MANAGED BUMBLE BEE NATURAL HISTORY

Bumble bees are social insects and live in colonies that have an annual cycle. Colonies are founded in the spring by mated, overwintered queens that initially work alone to provision their nest with pollen and nectar from spring flowers, and to produce workers. Over time, workers expand the nest and continue to forage and care for new worker sisters. At the end of summer, workers rear new queens and males. New queens mate and then enter winter hibernation; the old queen, workers, and males die before winter. Overwintered queens initiate new colonies in the spring to start the cycle anew. This contrasts with the multi-year lifespan of queen honey bees and the ever-present force of worker bees that keeps the colony alive and metabolically active throughout the year.

Bumble bees are considered generalist pollinators that visit a wide variety of flowers, and are attractive for pollination due to their ability to buzz pollinate (sonicate) flowers that require sonication to dislodge pollen (e.g., tomatoes, peppers, blueberries and cranberries). Using proprietary techniques, corporations are able to make bumble bee colonies available year-round, and they are well-suited for open-field, greenhouse, and tunnel pollination. These colonies are not retained by the consumer, so new colonies must be purchased annually.

ORCHARD MASON BEE NATURAL HISTORY

Solitary bees used for specialty crop pollination are cavity-nesting species belonging to the genus *Osmia*. After overwintering as adults in cocoons, these bees are ready to emerge, mate and forage



The managed Japanese hornfaced bee (*Osmia cornifrons*) is being developed for cherry and apple pollination. Photo by Emily May, The Xerces Society.

on spring crops in cool climates. (There are also Osmia species that occur naturally later in the summer, but their commercial use has not yet been sought or is in early development.) Adult Osmia females live only 6 to 8 weeks and readily nest in artificial tunnels provided by the bee manager or grower. Eggs are laid in individual cells on provisions of pollen and nectar collected by the mother bee, and each larva develops on its own mass provision. Depending on the Osmia species, partitions that separate each brood cell in the nest tunnel are made of mud, resin, masticated leaves or a mix of those materials. Only a single generation of Osmia bees are active each year. Therefore, all offspring produced in a season overwinter as adults in cocoons and won't emerge until the following year.

ALTERNATIVE MANAGED BEES AS CROP POLLINATORS

MANAGED BUMBLE BEES

The value of bumble bee pollination in greenhouses is widely acknowledged, and open field studies show that the Common Eastern Bumble Bee (Bombus impatiens) can be an effective pollinator of lowbush blueberry in eastern Canada and watermelon in North Carolina. Additional studies suggest limited benefits of bumble bees in open fields and that those benefits may be context dependent. In recent trials from researchers with the Integrated Crop Pollination Project, commercially-produced bumble bee colonies were added to fields of regionally-specific highbush blueberry varieties (approx. 2-4 colonies per acre) in British Columbia, Michigan, and Florida. These fields also were stocked with typical rates of honey bees, so this was a test to determine whether addition of the bumble bee colonies improved pollination. In the farms where wild bumble bees were observed, commercial bumble bees did not contribute to improved floral visitation. Overall blueberry yield was not improved by adding commercial colonies in most situations, because honey bee and wild bee visitation satisfied the pollination services needed. Therefore, in these contexts, the value of adding commercial bumble bees seems limited. Nonetheless, some growers consider the application of commercial bumble bees as pollination insurance for when weather conditions are not favorable for honey bee foraging.



Managed bumble bees are being deployed in Florida watermelon fields. Photo by Mary Bammer, University of Florida.

Bumble bees have also been considered for use as pollinators of pumpkin and watermelon. In New York and Pennsylvania pumpkin fields and in Florida watermelon fields that were supplemented with bumble bees (2-4 colonies per acre) and sometimes also honey bees, the high density of wild bumble bee colonies and other bees from the surrounding landscape suppressed the detection of any contributions of the added bumble bee colonies. In other pumpkin- and watermelon-growing regions where wild pollinators are in short supply, the addition of bumble bees may be an effective strategy to enhance yield. However, as with other alternative managed bees, care should be taken to use pathogen-free colonies in order to avoid releasing diseases into wild bumble bee populations.

ORCHARD MASON BEES

These bees collect pollen on their abdominal scopae, leaving it dry so that pollen grains are easily brushed onto the stigma of the next flower visited. They are less methodical in their foraging compared to honey bees, so they are more inclined to move between orchard rows rather than staying within a planted row when moving between flowers. This behavior renders orchard mason bees more likely to spread pollen from one variety to another, which is required for successful pollination of apple and almond. Blue orchard bee (*Osmia lignaria*) foraging activity can result in increased almond fruit set and nut yield; this is most apparent near nesting sites. Similarly, in Michigan and Pennsylvania tart cherry orchards, researchers found that yield increased in trees close to Japanese hornfaced bee (*Osmia cornifrons*) nesting sites.



Orchard mason bees carry pollen on hairs on the underside of the abdomen. These hairs are called scopae. Photo by Emily May, The Xerces Society.

There are a number of different kinds of orchard mason bees (genus Osmia) used as alternative managed pollinators.

• For apple and cherry pollination in the United States east of the Rocky Mountains, the eastern subspecies of the blue orchard bee (*Osmia lignaria lignaria*) and the introduced Japanese hornfaced bee (*O. cornifrons*) can be effective alternative managed pollinators.

• In the western U.S., the western blue orchard bee (*O. lignaria propinqua*) is an efficient pollinator of almond, apple and cherry.

• Where late spring weather impacts raspberry pollination in regions of the northwestern United States, blue orchard bees may be employed to set fruit and assure high druplet counts. In greenhouses, blue orchard bees were at least as efficient raspberry pollinators as honey bees. The endemic northwestern orchard mason bee (*Osmia aglaia*) is also a manageable and very efficient caneberry pollinator, but it does not fly under as cool and wet conditions as does the blue orchard bee. Ongoing research is exploring the ability to manage blue orchard bees using prescribed temperature regimes that synchronize adult bee emergence with late spring blooming raspberry cultivars.

Grower spotlight: Brian Campbell Farms (Pennsylvania pumpkins)



Brian Campbell was able to reduce his honey bee stocking rate due to the abundance of wild bees, like these squash bees, visiting his pumpkin. Photo by Katharina Ullmann, The Xerces Society.

Brian Campbell, of Brian Campbell Farms in central Pennsylvania, began farming at a young age; at age 14, he started a popular produce stand selling sweet corn and vegetables in Berwick, PA. After attending college at Penn State University, he returned home, rented 200 neighboring acres, and began farming and marketing vegetables. Since then, his farm has expanded to a 2,000-acre diversified business growing pumpkins, sweet corn, broccoli, and other vegetables. His 400 acres of pumpkins are sold in Wal-Marts across the northeastern US.

Five years ago, Brian began working with Penn State University researchers interested in native bee populations in central Pennsylvania. Students in the lab of Dr. Shelby Fleischer, a research partner on Project ICP, captured bumble bees in several of Brian's fields and analyzed the DNA of captured specimens to determine how many colonies were present in the area.

"I didn't know much about bees when they started collecting bees here," Brian explains, "but I wanted to learn more about the life cycle of different native pollinators and how that impacts everything." He began to pay more attention to the bees he was seeing in his fields and the surrounding natural areas, and how the practices he was using in his fields might affect those pollinators. "Some bees are ground-nesting, so we may have a pumpkin field where they're nesting and overwintering. The disking I do for crop management might be hurting those bees. That led me to look at other practices I can use to support native pollinators."

As Brian began to pay more attention to the pollinators in his fields, he realized that he had strong native bee populations in fields surrounded by good habitat. At the time, he was bringing in one

hive of managed honey bees per acre for pumpkin pollination, the standard stocking rate. "Since I became more aware of the native pollinators, I cut back my honey bee rentals to ½ hive per acre," Brian says. "At \$135/hive, that is a substantial cost savings." He says the relationships he had with the Penn State researchers and his beekeeper allowed him to feel comfortable cutting back on hives in all fields except those where he sees low bee activity in early spring. Four years later, he has no regrets.

In addition to cutting back on managed hives, Brian is now testing and implementing a variety of practices to support his native bee populations, including switching to no-till management for his pumpkin fields, planting floral provisioning strips on field edges, allowing flowering cover crops to bloom before termination, and cutting back on insecticide use. "We've really changed a lot of our spraying so that we're not spraying when bees are active," says Brian. "Turns out you can wipe out a lot of native pollinators if you spray them in the field." Researchers on Project ICP are monitoring the early spring and late summer flowering cover crop strips to see whether they benefit wild bumble bee populations and pumpkin pollination in Brian's fields.

Brian Campbell Farms uses farm practices that support wild pollinators, including planting flowering cover crops and using no till practices. Photo by Emily May, The Xerces Society.





Use shade structures to keep managed bumble bee colonies from getting too hot. Photo by Emily May, The Xerces Society.

USING ALTERNATIVE MANAGED BEES TO PROVIDE POLLINATION SERVICES

The following considerations should be kept in mind when using alternative managed bees for crop pollination:

BUMBLE BEES

- Managed bumble bees can be used in greenhouses and open fields, but care should be taken to purchase native, disease-free bees. If managed bumble bees are used in a greenhouse, set up screens in air vents and fans to keep them from escaping the greenhouse. Note: managed bumble bees use is restricited in some states. For example, Oregon does not allow the use of imported non-native bumble bees and in Caliornia managed bumble bees cannot be used in open field settings.
- Place order for managed bumble bees 3-4 months prior to bloom, as the provider needs weeks to grow new colonies. Bumble bees are sold as single colonies or "quads", e.g., four colonies in a weatherproof container.
- Managed bumble bees can be used alone or in combination with honey bees. Bumble bee colonies should be kept 100 yards (~90 meters) from honey bee hives to reduce the risk of honey bee robbing. Stocking rates will depend on the crop and whether you use honey bees. Your local extension agent and/or the bumble bee supplier can advise you on specific stocking rates.
- Managed bumble bees can fly miles from their nest to forage, but should be spread out evenly in open fields. For ease of use, they are often placed along field edges, but improved pollination is expected if they are distributed throughout the field. Be sure to place them out of the risk of being hit by tractors or other farm equipment.
- Bumble bees prefer cooler conditions and can forage in temperatures as low as 45°F. However, their brood can suffer when temperatures are too high. They do best between 46°F and 82°F. Shade structures can be placed over the colony to reduce the sun's intensity.
- Place bumble bees on top of pallets to minimize pest pressure (e.g., vertebrates, ants) and risk of flooding.
- Bumble bees should be placed in the field when the crop is at 5-10% bloom.
- As with other bees, managed bumble bees should be protected from pesticide exposure.
- Managed bumble bees should be disposed of at the end of the season by freezing the colony in order to reduce the potential escape and spread of disease into the wild bee community.

ORCHARD MASON BEES

- Secure a supply of orchard mason bees prior to the pollination season. Contact the Orchard Bee Association (orchardbees.org) to find an orchard bee supplier.
- Orchard mason bee stocking rate will depend on your crop, geographic region and which orchard mason bee you use. In the case of California almonds, researchers recommend 250-300 "nesting" blue orchard bee females per acre. However, it is typical practice to release more bees per acre than recommended, because female blue orchard bees often disperse from commercial sites (for reasons not fully understood), and the larger number assures an effective number of locally nesting bees. For example, blue orchard bee managers typically release ~800 females per acre for almonds, though only approximately one-third are found to occupy



Hundreds of blue orchard bees are released from central locations in almond orchards. They'll go on to mate and then build nests in nesting structures set up throughout the orchard. Photo by Derek Artz, USDA-ARS.

tunnels at provided nest sites under current management practices and environmental conditions. Project ICP researchers recommend releasing 400 female and 600 male blue orchard bees per acre in addition to using a full or reduced rate of honey bees.

- Prior to bloom, distribute shelters containing appropriately-sized tunnels (usually made of wood or cardboard) throughout the orchard. Contingent on orchard management requirements, large shelters with many nesting tunnels are erected on the edges of orchards, while smaller shelters with fewer tunnels can be distributed uniformly throughout the orchards by placing them directly in trees. The number of nesting tunnels these bees require for nesting and pollination varies by crop, so confer with your bee supplier to determine the number of shelters needed per acre.
- Also talk to your bee supplier to confirm spacing between nests. Spacing will depend on the orchard mason bee species and the farm context. For example, field observations of female Japanese hornfaced bee activity on Pennsylvania cherry blossoms revealed that released bees visited trees more than ~150 ft (50 m) from nest sites and increased yield in this self-fertile crop. However, the females may travel up to 600 ft (200m) for forage before the onset of cherry bloom. Blue orchard bees in the Central Valley of California, on the other hand, will travel even longer distances, at least 2,400 ft (800 m), to gather resources from non-crop flowers once almond bloom ends.



In order to pollinate, orchard mason bees need places to nest. Nesting shelters can be distributed in and around the orchard. Photo by Karen Powers, Michigan State University.

- Ensure that a supply of moist, clayey soil is available for bees to construct nest partitions.
- Orchard mason bees will arrive, prior to bloom, as loose cocoons. To assure the quick and synchronous emergence of healthy adult bees for spring crop bloom, use the management protocols for bee storage and incubation in "How to Manage the Blue Orchard Bee" (see Appendix 5), the industry standards available on the Orchard Bee Association website, or those recommended by your bee supplier. Given that this is an emerging industry, optimal management practices continue to be fine-tuned.
- For almond, release blue orchard bees when about 10% of the crop is in bloom. For Pennsylvania
 apple or cherry, Japanese hornfaced bees are typically released 5-7 days before bloom so that
 they can mate and establish nests. Confer with your bee supplier to determine the optimal
 timing of release for specific crops.
- Keeping all bees safe during bloom is of great concern. Limited or timely use of crop-protecting pesticides is always recommended to reduce pesticide risk to bees. Avoid spraying bee-toxic pesticides when bees are active in crop fields. Be aware that some pesticides applied prebloom, such as systemic pesticides, may end up in the pollen and nectar that are collected by bees for their offspring. Mud used to partition orchard mason bees nest cells also may be a source of contamination. Further investigations of routes of pesticide exposure are needed to determine how to avoid hazards to commercially managed orchard mason bees so that populations can be reliably obtained or sustained for pollination services.
- Remove bee shelters and newly formed nests from orchards when nest building has ceased. Monitor bees to determine when the adult stage is reached and continue to manage bees for successful overwintering (refer to management resources noted previously).

Despite the growing popularity of orchard mason bees for commercial pollination, mass production systems for these species are still being developed, and the largest supply of bees comes from trapping them in wild lands. Wild trapping is not only unreliable and possibly unsustainable, but it can be cost prohibitive. Furthermore, the use of bees in regions that differ from their locally adapted climates can disrupt natural developmental periods that result in management problems and a reduction in overwinter survival in some situations. A commercial supply of Japanese hornfaced bees is not readily available, and little is known about regional differences in their performance and development.

Orchard mason bees will use artificial nesting tunnels to build nests. Photo by Emily May, The Xerces Society.





Wild bees are diverse; they vary in size, shape, and color. Photos by (clockwise): Logan Rowe, Jason Gibbs, Karen Powers, Logan Rowe, Emily May, Jason Gibbs, all with Michigan State University.

WILD BEES

There are over 3,600 wild bee species in the United States and Canada. These wild bees vary in size, shape, color, life cycle, nesting habits, and diet. Bees of a particular species are all similarly sized, with the exception of some bumble bees, whose workers can be dwarfed by their queens. Bee weights range from the weight of a sesame seed (some sweat bees) to a coffee bean (honey bee) to a raw almond (queen bumble bee). A bee's size is broadly predictive of its foraging range. Tiny bees work within a few hundred feet of their nest, whereas foraging bumble bees can regularly fly several miles for bloom.

All bees visit only a few species during a given foraging trip. This behavior is known as floral constancy or fidelity and is good for pollination. However, over the course of their lifetime, most bee species collect pollen and nectar from diverse flowers to feed their offspring. A few bee species are restricted to a particular plant genus or family for all of their pollen needs. For instance, squash bees (*Peponapis* species) collect pollen only from squash, pumpkin, and gourd flowers. Blueberry, cranberry, and sunflower also have wild bee species that specialize on them. Most specialist bees are solitary with a single annual generation timed to match host bloom.

NATURAL HISTORY OF WILD BEES

LIFE HISTORY CYCLE

All bees pass through four life stages: egg, larva, pupa, and adult. The majority of wild bees are solitary. Females of solitary (non-social) bees construct, defend and provision their own nests. A small number of species nest communally, sharing a nest entrance but working independently, like separate homes in an apartment building. Some bees nest in close proximity in the soil; such aggregations can range from dozens to many thousands of nests. Though living closely together, each female still maintains her own nest.

In the case of solitary species, mother bees provision each offspring with an individual cache of pollen moistened with nectar. In some species the consistency is watery like gruel, but most are a thick paste. She lays a single egg on this pollen mass and seals the cell. The white, grub-like larva grows quickly in its cell, consuming the provision in 10-20 days (or slower in cool conditions). Most species then pass the winter as a larva. However, some early spring species and all *Osmia* bees overwinter as inactive cocooned adults. Our native social bees and carpenter bees overwinter as mated queens that store sperm in a special organ for later use.



Some bees like to nest near each other. Photo by Katharina Ullmann, The Xerces Society.

In the United States and Canada, only 6-7% of the 3,600 wild bee species are social, but social species tend to be the most commonly encountered bees, partly because they create large colonies. Unlike the European honey bee, which persists in perennial colonies, bumble bees and some sweat bees (e.g., *Lasioglossum*, family Halictidae) have annual colonies. These are founded by one or a few overwintering females who produce daughters that stay on as colony workers. Bumble bees colonies can range in size from 150 bees to 600 bees. Sweat bee colonies are smaller, with one to a few dozen workers. Bumble bees and most sweat bees mate in the fall. The mated females are the only individuals to survive the winter. New queens raise workers in the spring. These workers then collect pollen and nectar to bring back to the nest. At the end of the season the queen produces new queens and drones (e.g., male bees). The old queen, drones, and the rest of the colony will die in the fall, but new queens will overwinter after mating to start the process all over again.

NESTING HABITS

Most bee species nest underground. Below-ground nest entrances consist of a tiny mound of soil pushed out of a cylindrical, bee-sized hole dug by the mother bee. Nest entrances are usually the diameter of a pen or smaller, depending on the species that built the nest. Due to their small size, they can be difficult to find. Most bee species nest 6-24" deep, although some bee nests are found only an inch below the soil surface. Ground-nesting bees typically have a linear main burrow with short side tunnels each terminated by a somewhat enlarged chamber ("cell"). In some species, cells may be arranged in series or as a cluster. The soil of cell walls is smoothed and often coated with a thin waterproof secretion produced by the female. Among ground-nesters, only the alkali bee (Nomia melanderi) is intensively managed for agriculture. In southeast Washington, growers maintain nesting beds of millions of this bee to pollinate alfalfa for seed, and this is big business for those bee managers as well as for the growers that use these bees.



The majority of wild bees, like this digger bee (*Melissodes* speces) at her nest entrance, nest below ground. Ground-nesting bees can be found nesting in fields, orchards, field borders, and natural areas around the farm. Photo by Katharina Ullmann, The Xerces Society.

Bumble bees and some solitary species (e.g., some leaf-cutting bees) use pre-existing cavities in the ground. Bumble bee queens often choose abandoned nest burrows of small mammals (e.g., mice, gophers and chipmunks). Some bumble bees will nest in snug above-ground cavities (e.g., birdhouses, tree hollows, compost piles, and old mattresses).

The remaining bee species nest above ground. Most of these use old tunnels of wood-boring beetles left in dead wood. Some of these bees will nest in provided tubes or grids of tunnels. For example, blue orchard bees adopt drilled or grooved wooden blocks and leaf-cutting bees use moulded styrofoam nesting blocks. Other bees make nests in hollow or pithy twigs. For example, small carpenter bees (*Ceratina*) chew cylindrical tunnels in the pith of dead twigs (e.g., sumac, box elder) or brambles (rose, raspberry). A few solitary species make freestanding nests built from mud, leaf pulp, or resin and pebbles.

WILD BEES AS CROP POLLINATORS

Globally, wild bees are important crop pollinators; some wild bees are more effective on a per bee basis than honey bees for pollinating many crops. In some cases, wild bees are the most abundant pollinators – even when fields are stocked with honey bees. For example, researchers documented that, on average, more than 75% of visits to Pennsylvania pumpkin flowers were from wild bees. In addition, half of the apple growers and many of the peach growers in Pennsylvania rely solely on wild bees for pollination - this is likely due to the abundance of wild bees and the low pollination needs of apple and peach. Watermelon, pumpkin, blueberry, hybrid sunflower, almond, sungold tomato, sweet cherry, apple, and cranberry all benefit when farms harbour diverse and abundant wild bee communities.

Wild bees are most abundant and diverse in fields and orchards near natural and semi-natural habitat that provide nesting sites and floral resources. In addition, diversified farms tend to have more abundant and diverse pollinator communities than monocultures. As mentioned previously, some wild bees specialize on crop plants. For example, the southeastern blueberry bee (*Habropoda laboriosa*) specializes on blueberries in the Southeast while the miner bee, *Andrena carolina*, depends on cultivated blueberries and their wild relatives in Michigan.

Many wild bees are extremely efficient pollinators. For example, unlike honey bees, some wild bees like the digger bee, *Anthophora urbana*, have the ability to buzz pollinate, or to vibrate their flight muscles at a high frequency to release the pollen of blueberry, cranberry, and nightshade family crops (tomato, eggplant, etc.). Large bees, like bumble bees, are able to transport large amounts of pollen between flowers. Miner bees in the genus *Andrena* are abundant spring flying bees that are more effective pollinators of orchard crops than honey bees on a per visit basis, likely because of how they handle flowers.



The miner bee, *Andrena carolina*, specializes on blueberry pollen and is an important pollinator of Michigan blueberry. Photo by Emily May, The Xerces Society.

Abundant and diverse wild bee communities mean that wild bees can complement each other's pollination abilities given that different bees tend to pollinate at different times of the day and under different weather conditions, and to visit different parts of the plant as well as different parts of the flower. Finally, as described above, wild bees can also make honey bees more effective pollinators by disrupting their usual behavior, causing them to cross pollinate more often.

USING WILD BEES TO PROVIDE POLLINATION SERVICES

Most growers, whether they know it or not, have wild bees in their fields, orchards, or groves supplying crop pollination. The following considerations should be kept in mind if using wild bees for crop pollination:

- Take some time to notice how many different kinds of bee species visit your crop flowers. For reference, more than 100 bee species were found in Michigan blueberry fields and New York apple orchards, over 80 bee species were found in Michigan tart cherry orchards, more than 50 bee species were found in Pennsylvania apple orchards, and 19 bee species were found in California almond orchards.
- If there are enough wild bees visiting crop flowers, fields do not need to be stocked with honey bees.
 However, many farms, especially large, intensive monocultures far from natural areas will not have enough wild bees to support their crop pollination needs.



Bumble bees are important pollinators in many cropping systems. Photo by Emily May, The Xerces Society.

Take stock of and protect the natural and semi-natural Arces Socie habitat (e.g., meadows, forest fragments, hedgerows, and wildflower strips) surrounding your crop fields. Wild bees rely

and wildflower strips) surrounding your crop fields. Wild bees rely on the floral and nesting resources these areas provide – especially when the target crop is not in bloom.

- Consider adding floral resources to your farm fields or edges by planting a flowering crop, flowering cover crop or understory, wildflowers, and/or blooming shrubs and trees that are attractive to wild bees.
- Consider protecting and/or supplying nesting resources. For example, snags of wood and
 pithy stemmed plants for above ground nesting bees and undisturbed areas, free from tillage
 and heavy thatch are used by ground nesting bees. For bees that require special materials
 to make nests (e.g., mud and leaves) make sure those materials are available and free from
 pesticides.
- As with managed bees, wild bees need protection from pesticides. They may be more vulnerable than managed bees given that they cannot be removed from fields Avoid exposing wild bees to bee-toxic pesticides and remember that these bees may be visiting flowers in the understory or returning to nest sites below your crop field even when the crop is not in bloom.

Grower spotlight: Cherry Lane Farms (Michigan Tart Cherry)

Jeff and Nita Send of Cherry Lane Farms grow 800 acres of tart and sweet cherries in northern Michigan, the largest tart cherry production region in the United States. While the majority of Michigan tart cherry growers use honey bees to pollinate their crop, some growers, like the Sends, are relying on wild bees and an alternative managed bee called the Japanese hornfaced bee (*Osmia corniforns*) in addition to the honey bees they rent.



Jeff Send grew up working on his grandfather's 40-acre farm and orchard. Jeff recalls that as a child he saw a lot of wild bees and then, at some point, there were fewer. He

Nita and Jeff Send. Photo by Emily May, The Xerces Society.

says, "Now, I think the wild bees are coming back." "Slowly," adds Nita Send. Over the past three years, Michigan State University researchers have found 81 different species of wild bees, in addition to honey bees, visiting Michigan tart cherry during bloom.

The Sends collaborated with Project ICP researchers to seed a wildflower planting next to one of their orchards in 2013 and to evaluate the potential for using managed Japanese hornfaced bees in another. With the wildflower planting they hope to boost the populations of both wild and managed bees on their farm. The wildflower mix, designed to bloom outside of cherry bloom, provides pollen, nectar, and nesting sites for wild bees. "I think it's a great combination...maybe we'll recapture more of our wild bees," says Jeff Send. Preliminary findings from Project ICP researchers are promising; they discovered that almost 30% of the bees found on pollinator plantings are also found visiting tart cherry. With the managed Japanese hornfaced bees they hope to increase pollination during inclement weather when honey bees are less reliable.

In addition to planting wildflowers, the Sends modify their spray program in order to minimize any negative impacts on bees. ""You want to be aware of what you're spraying on those trees [and] when you're spraying it on the trees," says Jeff. "Bees are #1; when they're out there, we stay away."

This wildflower planting next to a Send tart cherry orchard doesn't look like much in the fall, but in the spring it is rich with blooming wildlowers. Photo by Katharina Ullmann, The Xerces Society.



Farm practices to support crop pollination

WHAT DO BEES NEED?

Understanding the resource needs of bees provides the foundation for management practices that support bees on farms. There are three main things bees need to be healthy:

Access to food (pollen and nectar) and water. • Pollinating bees visit flowers to collect food they use to support their own daily energetic and nutritional needs and to provision their developing larvae at the nest. Adults and larvae require a combination of pollen and nectar and these two resources cannot be substituted for one another. So, flowering plants that provide both pollen and nectar are essential. Adult bees forage out from a central nest (be it a solitary tunnel or a colony), so these flowers must be within the flight range of the adult. Also, the adult life span of many bees species lasts longer than the bloom of any one flower species, so a mixture of flowering species is needed to ensure reliable



Bees need access to pollen, nectar, and nesting resources, and protection from pesticides in order to thrive on farms. Photo by Kelly Gill, The Xerces Society.

resources over time. In addition, bees vary in their size and shapes, meaning different bees can access the pollen and nectar of different plant species, so a diversity of flowers supports greater diversity of pollinator species. Finally, pollen from different plants varies in protein content and other nutritional qualities so a diverse pollen diet is healthiest for bees. Other pollinators such as flies and wasps use similar resources to wild bees, so enhancing farms for wild bees should enhance many of these other insect species. In addition to needing pollen and nectar, honey bees need access to pesticide-free water when regulating hive temperatures.

- Access to nesting resources. Beekeepers provide managed bees with nesting structure, but wild bee species depend on the farm environment for nesting structures. Most wild bees are solitary ground-nesters so they require bare or semi-bare ground to tunnel into for nests. About one third of wild bee species nest in wood tunnels, so leaving old snags with beetle tunnels or pithy plant stems can provide nesting sites for these species. Bumble bees can nest in bunch grasses, brush or rock piles, or old rodent burrows. Along with appropriate nesting sites several species collect additional matierls for nest construction. For example, as their names suggest, mason bees (genus *Osmia*) use mud, leafcutter bees (genus *Megachile* and many *Osmia*) use leaf pieces, and wool carder bees (genus *Anthidium*) use plant hairs.
- A safe environment where there is minimal exposure to pesticides. Although insecticides, fungicides and herbicides can be integral parts of agricultural management, it is important to provide refuge from environmental toxins in order to maintain healthy populations of crop pollinators on farms. This is critical during crop bloom but safe haven from pesticides is important year round for bees on farms.



Natural areas around farms can provide pollen, nectar and nesting resources. Photo by Emily May, The Xerces Society.

Flowering wild plants, like this willow, can provide extra pollen for wild and managed bees. Photo by Emily May, The Xerces Society.

MAINTAINING HABITAT FOR BEES: KNOW AND PROTECT WHAT YOU HAVE

Crop pollinating bees benefit from habitat around fields. Studies from around the world have documented the importance of natural and semi-natural habitats for supporting wild bee populations on farms. Surveys of bees on crop fields consistently show that bee numbers and diversity increase near natural areas. These patterns suggest natural habitats can act as a source of bees for neighboring farms. Natural areas are likely providing nesting habitats, from which bees fly to gather resources at flowering crops, and also offer pollen and nectar resources when crops are not blooming. In addition, honey bees will use these natural and semi-natural areas to collect nectar, pollen and propolis.

The most cost-effective step you can take in supporting pollinators on your farm is to recognize and protect existing bee habitat near your fields. Different bees need different floral and nesting resources, so it is best to maintain a diversity of habitat types including some areas that are more stable over time and others that are more frequently disturbed (e.g., mowed or tilled on occasion). Some bee species require woody material or plant stems for nesting, while ground-nesting bee species have differing requirements for soil composition (e.g., clay vs. sand), compaction, cover and moisture.

In addition, habitats differ in their ability to support crop pollinating bees throughout the season. For example, forest and dense woodland habitat may provide short-lived pollen and nectar resources for bees in early spring when wildflowers bloom on the forest floor, but once trees leaf out, the resulting dense shade limits floral resources within and likely deters bees, whose activity seems to correlate with sunlight.

Farming itself affects bee communities in a variety of ways. For example, clearing woody vegetation from fields reduces the availability of above ground nesting sites. Similarly, frequent tilling to control weeds or prepare beds may disturb ground-nesting bees found on field borders, in crop fields, and along farm roads. Ironically, long-term protected areas like hedgerows might reduce nesting sites for ground-nesting bees through thatch build-up or development of a hard crust on dry undisturbed soils that ground-nesting bees are unable to dig into. It appears that moderate, occasional disturbance to the soil surface may benefit some bee communities.

Woodlands or riparian areas near fields can provide nesting locations as well as nectar and pollen from flowering plants, and edges of woods can be easily enhanced by planting springand summer-blooming shrubs and trees to support widl and managed pollinators of spring crops. If fields are not being repeatedly sprayed for pest control then blooming cover crops or a blooming understory planting can provide additional resources through the summer. All of these strategies can be less expensive than installing a flowering hedgerow or wildflower planting. However, wildflower plantings are especially good at providing a high density and diversity of flowers for managed and wild bees, and also appear to enhance nesting opportunities for ground-nesting bee species.

Michigan blueberry fields next to wildflower plantings produced higher yields than those next to mown, weedy edges. Photo by Emily May, The Xerces Society.



HABITAT AUGMENTATION: HELP BEES BY ADDING POLLINATOR PLANTINGS

Bees benefit greatly from habitat plantings on farms. Plantings of wildflowers and flowering hedgerows along field margins, road verges, and uncropped areas on the farm all can provide the floral and nesting resources bees need. Wildflower plantings and hedgerows almost always greatly increase the abundance and diversity of target pollinators and the pollinator community as a whole compared to unmanaged areas.

Habitat plantings to support pollinators can be flexible in terms of the types of vegetation planted, and their placement and configuration in the farm landscape. Hedgerows and wildflower strips, as the names suggest, are linear features that often fit in along field margins, road verges or irrigation ditches. Hedgerows are dominated by flowering woody shrubs and trees, providing both food and nesting resources for bees. Wildflower strips along field edges can include both perennial and annual wildflowers, and they may be combined with a row of shrubs. Meadows are established on larger areas, and are dominated by wildflowers. These are typically placed in fallow or uncropped areas where crop production is sub-optimal due to low-lying, too wet, too dry, frosty, or unusual pH soils. In many cases native wildflowers or shrubs can thrive in these sub-optimal conditions because they are adapted to the local environment. Wildflower plantings and hedgerows differ in the amounts and types of resources required for establish, but less effort to maintain over the long term. They also tend to have lower floral density than wildflower strips or meadows.

Flowering plantings can provide extra pollen and nectar for managed bees, like this honey bee. Photo by Katharina Ullmann, The Xerces Society.



Regardless of the type of vegetation planted, how close a habitat planting is to a crop field may impact its ability to bolster pollination services. There are few studies testing the influence of habitat placement and size on pollination services to crops and their economic benefit for growers. However, computational models suggest greater benefit from large, close plantings with smaller crop field size. In practice habitat placement and size is often determined by where uncropped land is available, and adding multiple plantings throughout a farm will provide the greatest benefit to bees.

There is strong evidence that wild bees benefit from the floral and nesting resources that onfarm habitat provides. Furthermore, in many cases, important crop pollinating bee species



In addition to providing pollen and nectar, flowering plantings provide areas where ground-nesting bees, like this miner bee, can nest. Photo by Emily May, The Xerces Society.

specifically benefit from habitat plantings – including planted wildflowers and grass margins. While some growers express concern that wildflower plantings might draw bees away from their crop, a study from California found that wildflower plantings next to almond orchards did not reduce bee activity in the orchard.

Although our understanding of the resulting benefits to crop pollination are much more limited, preliminary evidence for adding pollinator habitat is encouraging. Striking benefits have been shown for some perennial crops including both berries and tree fruit. Researchers in Michigan found that highbush blueberry yields were 10-15% higher in fields next to wildflower plantings compared to fields without wildflower plantings. Lowbush blueberry in Maine showed similar results with added habitat for pollinators. In the United Kingdom, growers who planted wildflowers next to their strawberry fields had 25% more bees visiting their strawberry flowers than fields that lacked a wildflower planting, and previous research showed that the more bees that visit strawberry flowers, the higher the fruit set.

Planted wildflowers and hedgerows can take a few years to establish dense blooms. In Michigan, it took roughly four years for wildflower plantings to provide a return on investment. In California, it took roughly 7 years for hedgerows supporting both pollinators and natural enemies that provide pest control services, to provide a return on investment. However, yield benefits are not guaranteed; a recent study in hybrid sunflower seed found that adding hedgerows next to seed fields did not increase sunflower seed yield in California. There is still much to learn about the context in which pollinator plantings benefit crop yields.

Five Steps to Success for Establishing a Pollinator Planting

Although the specifics of when and what to plant will depend on the region and climate you live in, the following guidelines apply universally to all regions. Confer with your local cooperative extension agent, USDA-Natural Resources Conservation Services office, pollinator conservation expert, or native plant nursery for additional information on which plants to select and the best timing for seeding. Watch the <u>Pollinator Habitat Planting series</u> on the Integrated Crop Pollination Project Youtube page for more information.

1. *Pick a good site:* Choose a site that is sunny and fairly well-drained. Avoid sites with aggressive, hard-to-control weeds. Choose a site that will not be exposed to pesticide drift from adjacent fields, or consider installing a drift barrier or wildflowers that can be mowed during pesticide application periods.

2. Kill the weeds (before seeding): Most sites will need at least one full year of weed eradication before seeding. This step is essential to establishing a successful planting. Chemical weed control will require at least one full year of repeated herbicide treatments to knock back weeds from all seasons (cool and warm seasons). Sites with high weed pressure or more aggressive weeds will require up to three years of weed control prior to planting pollinator habitat. Solarization can also be used in regions with long, hot summer weather. Planting sites should be disked, irrigated, immediately covered with UV stabilized clear plastic (such as high tunnel greenhouse plastic) and sealed by burying all edges no later than June 21. The resulting greenhouse cooks the seed within the top soil layer. Check the plastic for rips and tears throughout the growing season, especially in areas where deer are abundant. Repair any rips in the plastic using greenhouse plastic



Solarization is a form of weed control prior to seeding. This process includes laying down clear plastic to raise soil temperatures and destroy germinating weed seed. Photo by Sarah Foltz Jordan, The Xerces Society.

repair tape to prevent losses of temperature underneath the plastic. Do not till the soil after using any of the above weed control strategies. Tillage will bring dormant weed seeds to the surface, where they will germinate and compete with wildflower seeds for soil, water, and light.

3. *Choose the right seed mix:* Plant species that are native to your area. These plants are more likely to be adapted to your local conditions. Choose species that are visited by pollinators and provide a diverse array of continuous bloom. See "Additional resources" at the end of this guide for plant lists.

4. *Seed it well:* Native seed mixes will include seeds of different sizes. Use a bulking agent like cornmeal, sawdust, cracked corn, or sand, and mix it well to help distribute the seed more evenly before seeding. There are a number of seeding methods to choose from: seeding by hand can work well for small plantings, a hand-held broadcast seeder for larger plantings, or a drop seeder that gradually dispenses seed as it is pulled across a field. These are all effective for dispersing seeds evenly. Ensure that seeds are in contact with the soil by using a roller after the seeds are distributed. In many regions across the US, native wildflowers are typically seeded in fall so they experience a winter before germinating.

5. *Kill the weeds (after seeding)*: It is critically important to monitor the planting during the first year to control weeds when wildflower seedlings are getting established. Weed control may include regular mowing at 6-8 inches to prevent flowering weeds from setting seed or using an herbicide or flame weeder to spot-control weeds. Hand weeding may also be appropriate depending on the planting size. Continue to manage weeds in subsequent years as needed, so the seeded species can grow.



Wildflower plantings can provide important resources for bees, like this long-horned bee (*Melissodes* sp.) on cup plant (*Silphium perfoliatum*). Photo by Emily May, The Xerces Society.

2014 Farm Bill Programs that Provide Pollinator Related Cost-Share Opportunities to Farmers

Cost-Share Program	Funding Agency	URL	
Environmental Quality Incentives Program (EQIP)	Natural Resources Conservation Service (NRCS)	bit.ly/2gofEG9	
Conservation Stewardship Program (CSP)	NRCS	bit.ly/2fN3TW7	
Agricultural Conservation Easement Program (ACEP)	NRCS	bit.ly/2fN3Eup	
Conservation Reserve Enhancement Program (CREP)	Farm Service Agency (FSA)	bit.ly/2fN5Lya	
Conservation Reserve Program (CRP)	FSA	bit.ly/2fN5Lya	

For more details see this USDA document: http://bit.ly/2fp8rRO

HORTICULTURAL PRACTICES

Modifying horticultural practices is another way to enhance crop pollination and support wild and managed bees; pollination can interact with other management practices (e.g., pest, nutrient, and water management) to influence yield. For example, in canola fields, pollination can make up yield deficits due to poor nitrogen availability and vice versa.

Fields, orchards, and crop margins can be managed to enhance floral and nesting resources. For example, reduced mowing and autumn cultivation of field margins, and maintaining fallow areas may increase the diversity, abundance, and duration of flowering plants for bees.

Depending on the scale and types of crops being grown, crop diversity across the farm is also likely to benefit bees. For example, in New York farms, strawberry fields benefited from bees spilling over from nearby apple orchards after the apple crop had finished bloom. In addition, diversifying the number of blooming plants on the farm (including blooming crops) increases bee abundance



Blooming understory plantings can provide bees with additional resources. Care should be taken, though, to mow flowers before any chemical applications are applied. Photo by Emily May, The Xerces Society.

and diversity. For example, researchers in Brazil found that peppers intercropped with flowering basil were larger and produced more seed than those grown alone. Field size is another factor that can influence crop pollination. In Michigan highbush blueberry, for example, small fields had more wild bees visiting them than large fields stocked with honey bees.

Crop fields also may provide nesting sites for bees. Examples are still limited, but studies from different crops (e.g., sunflower, pumpkin, and blueberry) have found high nest densities for important crop pollinators within the field themselves. This appears to be particularly important for specialist bees, which nest in association with a crop plant that they pollinate. For other soil-nesting

species in regions with dry and hard packed soils, light to moderate, shallow tillage in spring and with no disturbance during the rest of the summer may provide valuable conditions for nest establishment. However, tillage can also disturb the nests of many soil-nesting species. Therefore, leaving some areas of the farm untilled or reducing the frequency or depth of tillage may benefit bees. The importance of fully undisturbed soils probably varies among bee species. This is an active area of research to determine what conditions and practices soil nesting bees need to select and excavate a site for their nests and, subsequently, to be able to emerge from that nest.

Pollinator friendly cover crops also may benefit bees. This is a promising option for some systems (e.g., fruit orchards or late season row crops like pumpkin) where timing or specific crop configuration might allow for additional planting. For example, alleyways between orchard rows could be augmented with carefully selected plants that benefit pollinators and also provide other benefits to tree crops (e.g., nitrogen fixation).

Case Study: ICP for California Almond

Each crop has a different seasonality for bloom, and is grown in a different regional, climatic, soil, or management context. For example, almond is grown in regions with a Mediterranean climate that have rainy winters and long hot summers. In California, almond is among the earliest blooming plants in the region, flowering for a very short period before most native bee species are active. Pollination therefore relies primarily on managed honey bees, and millions of colonies are trucked to the region to provide pollination services each spring. However, integration of managed blue orchard bees (Osmia lignaria propingua) can increase almond pollination, and the presence of even modest numbers of wild native bees can interact synergistically with honey bees to increase their pollination effectiveness. The short, early bloom of almond and its reliance on honey bees mean that plant species selected for habitat to support almond pollination must be tailored to provide resources very early in the season to nourish bees before and then immediately following crop bloom. Later flowering species may also help increase honey bee hive strength or the reproductive success of blue orchard bees that are not immediately removed from orchards following crop bloom. Cover crops of mustards and clovers have been promoted for planting in alleys between tree rows and native plant species have also been used; however in both cases more testing is required to understand the benefits for bees and almonds. A key concern of growers is whether pollinator plantings might compete with the orchard for bee visits to flowers, but the research findings so far indicate no significant competitive effect.



Blue orchard bees mate after being released. Females then begin to build nests in tunnels supplied by the grower. In the process she visits and polinates almond flowers. Researchers found that blue orchard bees makes honey bees better pollinators. Photo by Derek Artz, USDA-ARS.

MANAGING PESTS WITH POLLINATORS IN MIND

Pest management is a key component of successful crop production. Many growers use integrated pest management (IPM) in order to minimize the use of pesticides. IPM relies on a combination of management practices, including preventative measures like selecting resistant varieties, removing infested plant material, and using row covers and responsive measures, like using mechanical or chemical controls. Biological control can act as a preventative or responsive control, depending on how it is used. In addition, IPM promotes the use of crop scouting and economic thresholds to make decisions related to chemical controls. Current efforts to explicitly integrate pollinators into the IPM framework are being called Integrated Pest and Pollinator Management (IPPM).

What is Integrated Pest and Pollinator Management?

Most growers are familiar with the concept of Integrated Pest Management (IPM). IPM is a pest management approach that integrates multiple control measures e.g., biological, physical, cultural, and chemical controls. Many of these measures act as preventative measures, reducing pest build up to prevent or reduce the need for pesticide applications. In addition, IPM relies on field scouting and an understanding of pest and natural enemy ecology to make targeted pest management decisions. IPM does not prohibit the use of pesticides, but aims to target the most susceptible pest stage at the optimal timing with the most pest selective products that will also minimize risks to humans and non-target organisms in the environment.

Integrated Pest and Pollinator Management (IPPM) is an extension of IPM that explicitly takes all pollinators into account when managing pests, just like it has done with conserving biological control. Like Integrated Crop Pollination, IPPM, promotes the integration of multiple pollinators to supply pollination services. In addition, IPPM considers the chronic effects of pesticides on larvae as well as the acute effects on adult bees, where this information is available. Finally, IPPM specifically encourages pest management choices that minimize risks to pollinators. These choices take into account risks associated with pesticide toxicity and exposure and considers their impact on both managed and wild bees. Like IPM, integrated pest and pollinator management is a system that can be updated as new information is available on the non-target effects of pesticides on pollinators. To learn more about IPPM see the Additional Resources in Appendix 5.



Wild natural enemies, like this lacewing larva feeding on an oleander aphid, can provide free pest control services. Photo by Thelma Heidel-Baker, The Xerces Society.

Where possible, growers should aim to reduce pesticides by using preventative measures. Pesticides can have acute or chronic effects on bees. Acute effects result in death and are typically associated with direct contact with a highly toxic pesticide. Chronic or sublethal effects include behavioural changes, reduced reproduction and growth, memory impairment and increased risk of disease. Chronic effects are typically caused by long-term low level exposure to pesticides. In cases of suspected bee poisoning or bee kills it is important to notify the county agricultural commissioner's office and/or state apiarist. Signs of bee poisoning include large numbers of dead and dying bees and/or large reduction in foraging activity.

Most growers are aware that insecticides, including insect growth regulators (IGRs) and systemic insecticides, can be toxic to bees. Less obvious are the ways in which fungicides, adjuvants, surfactants and herbicides may impact bees. Fungicides are used for disease management and often sprayed when crops are in bloom. Recent research suggests that certain fungicides can harm both adult and larval bees. Of particular concern are tank mixes that include insecticides and some fungicides from the Fungicide Resistance Action Committee (FRAC) Group 3 fungicides. Some FRAC Group 3 fungicides have been shown to make insecticides more toxic to bees. In addition, avoid spraying captan, chlorothalonil, and mancozeb alone or in combination with other pesticides while bees are active in crop fields.

Tank mixes reduce the number of passes a sprayer will need to make, but careful selection of pesticides is needed to avoid using a combination that is toxic to bees. Adjuvants and surfactants can also harm bees when they come into direct contact with them, especially oils and soaps. Finally, while herbicides generally do not have a direct impact on bees, herbicide applications can indirectly affect bees by removing noncrop flower resources from fields and field edges. Given the desire to keep fields free of weeds, this highlights the benefit of adding pollinator habitat in protected areas elsewhere on the farm.



If using chemical controls, care should be taken to select the least toxic formulas and equipment should be calibrated to minimize drift. Photo by Natalie Boyle, USDA-ARS.

Pesticide risk to bees is a function of the pesticide's *toxicity* and the bee's *exposure* to the pesticide. Pesticide toxicity to bees is measured by identifying the pesticide dose at which 50% of adult honey bees die (the LD_{50}). The lower the $LD_{50'}$ the more toxic the pesticide is for adult honey bees. The EPA is currently making efforts to include other bee groups (e.g., wild social and solitary bees) and other life stages (e.g., honey bee larvae) in regulatory requirements for pesticide risk assessment. There are a number of resources available to help you identify pesticides that are less toxic to bees. See the resources listed in Appendix 5 for additional information. Remember that organic registration does not necessarily mean a product is safer for bees; check the LD_{50} for different products to determine their relative toxicity.

Bees can be exposed to pesticides in many different ways. They can come in direct contact with the pesticide when it is applied. Or, they can be exposed to pesticide residues on flowers while foraging for pollen and nectar. Adult bees can bring contaminated pollen and nectar back to their nest to feed their young. This is of particular concern for systemic pesticides, especially the nitroguanidine neonicotinoid insecticides that can be expressed in pollen and nectar up to several weeks after application to the plant foliage, roots, or via trunk injection. In addition, wild bees that collect mud or leaf material to build nests may line their nests with contaminated material. Honey bees actively collect water, and if water sources in farmland are contaminated with pesticides, this is another source of exposure.

How to Protect Bees from Pesticide Poisoning

1. Communicate with your beekeeper. Use written pollination agreements that include drop off and pick up dates, location of hive placements, number and strength of colonies, price, and plan to avoid or use pesticides carefully.

2. Use Integrated Pest and Pollinator Management (IPPM) methods to help prioritize use of non-chemical controls for pest management and to determine if and when chemical control is necessary based on pest scouting and economic thresholds. Talk with your local extension agent for more information on IPPM.

3. Follow label instructions, choose less toxic pesticides and avoid tank mixtures. See resources in Appendix 5 for more information.

4. Modify spray timings and reduce drift to minimize bee exposure to pesticides. Where possible, avoid spraying during bloom, do not spray in windy conditions, calibrate application equipment, and turn off spray nozzles at the end of rows and when passing near hives. Avoid dust and wettable powder formulations during bloom; these easily stick to bee hairs and flowers which bees visit. Always communicate with your beekeeper prior to using pesticides.

5. Mow flowering understories prior to spraying throughout the growing season. While managed bees can be removed from crop fields after bloom, wild bees may be present in and around crop fields both before and after bloom.



Minimize pesticide exposure to bees by removing flowering resources in fields or orchards prior to applying pesticides. Photo by Emily May, The Xerces Society.

Conclusion

Integrated Crop Pollination provides a framework to improve crop pollination. By combining pollinators (e.g., managed honey bees, alternative managed bees, and wild bees) and using management practices (e.g., habitat augmentation, horticultural practices, and pesticide stewardship) that support bees, growers can ensure that their crop receives optimal pollination. Given the link between pollination and crop yield, more and more growers are actively managing their pollination needs as carefully as their nutrient, pest and disease management, and water needs. The optimal combination of pollinators and management strategies will depend on the crop, farm conditions, and surrounding landscape. This is a growing field of study; both growers and researchers will continue to identify innovations that improve crop pollination and yield.

The Common Eastern Bumble Bee, *Bombus impatiens*, is one of the many wild bees that pollinate crops. Here, a Common Eastern Bumble Bee is visiting blooming asters next to a blueberry field that is ready to harvest. Photo by Emily May, The Xerces Society.



Appendix 1

INTEGRATED CROP POLLINATION CHECKLIST

This checklist will lead you through the opportunities and obstacles to optimizing crop pollination on your farm, with an emphasis on management steps associated with Integrated Crop Pollination.

Know your crop's pollinator demand

- □ **Know how dependent your crop is on pollination.** See Appendix 2 to determine how much your crop depends on pollinators.
- □ Know how dependent your crop cultivar is on pollination. Crop cultivars vary in how dependent they are on pollinators. Talk with your seed provider to deteremine the cultivar's pollinator dependence.
- □ Know how attractive your crop is to honey bees. For example, when you place a honey bee hive next to the blooming crop, do the honey bees readily visit the crop? See Appendix 2 for a summary of crop attractiveness to honey bees for a select group of crops.

Know how to optimally supply pollinators and ensure pollination

- □ Know the optimal stocking rates and best timing for placing colonies of managed honey bees. See Appendix 2 for recommended stocking rates for a subset of specialty crops. Typically, managed honey bees are placed in fields and orchards at 10% bloom. Hive placement should distribute bees evenly across the field or orchard, but be located in areas accessible to beekeepers and out of the way of pesticides.
- □ Know stocking rates for alternative managed bees, like bumble bees or orchard mason bees. Confer with your supplier of these bees to determine optimal stocking rates, timing, and placements of alternative managed bees.
- □ Know if wild bees visit and can pollinate your crop. Wild bees are known to pollinate a number of specialty crops and in some cases, make honey bees better pollinators. Abundant wild bees are more likely to be common on crops when (1) at least 30% of the area within 0.75 miles (1.2 km) of the field is in untilled land that has high densities of flowering plants, (2) there are abundant and diverse floral resources on the farm itself, and (3) less toxic pesticides are used during bloom and the rest of the season.
- □ Know the optimal combination of managed and wild pollinators. Pollinators include managed honey bees, several species of alternative managed bees (e.g., orchard mason bees), and different types of wild bees. Reliable and economical pollination may come from honey bees alone or from a combination of different pollinators. The optimal combination of pollinators will depend on the crop, the farm situation, and the economics of different approaches. Using farm practices that support crop pollinators can ensure that you get a full return on your pollinator investment: healthy bees providing optimal pollination.

Keep pollination records to track pollinator supply and demand

Keep pollination records. Record pollination strategies (e.g., pollinators used) and yield outcomes, ideally for each field or orchard and cultivar. Record weather conditions during crop bloom. If managed bees are used, monitor hive or colony strength and/or bee activity. Monitor crop bloom for pollinator visitation, including what types of bees are visiting the crop (e.g., honey bees, orchard mason bees, wild native bees). See the example data sheet (Appendix 3) to record pollination supply and demand.

Checklist to keep your crop's pollinators healthy and working hard

- □ Establish a contract with beekeepers or other bee providers to agree on expectations.
- □ Ensure that floral resources that provide pollen and nectar are available before and after crop bloom. Flowering resources can include wildflowers, trees and shrubs, and can be provided by blooming cover crops, small meadows, riparian areas, field borders, hedgerows, and/or nearby wood lots.
- □ Ensure that nesting resources are available and protected on farm. One out of three wild bees nest in above ground cavities (e.g., pithy stems, snags of old wood). Some of these bees, as well as some managed bees, require nest building materials (e.g., mud or leaves). The remaining 70% of wild bees nest below ground and require areas with undisturbed soil.
- □ Ensure that water and/or moist mud are available in dry environments. Honey bees need water to cool their hive and orchard mason bees need mud to build nest cells for their offspring.
- □ Minimize risks associated with mowing and herbicides. Mowing and herbicides can be useful for invasive weed control, but can also remove floral resources.
- □ Minimize risks associated with tilling. Tilling can destroy wild bee nests below ground. As much ground as possible should be left undisturbed.
- □ Minimize risks associated with insecticides and fungicides.
 - Use cultural and mechanical/physical practices to minimize pest outbreaks.
 - □ Use integrated pest and pollinator management to make targeted pest management decisions.
 - □ If chemical pest or disease control is needed, use options with the least toxicity to bees and time application to minimize bee exposure.

Appendix 2

POLLINATION NEEDS OF SELECT SPECIALTY CROPS

Table showing general pollination information for a select number of specialty crops, including their dependence on and attractiveness to pollinators, recommended managed bee stocking rates, and fruit set goals. For information on specific varieties or other crops and their dependence on pollinators check with your extension or farm advisor, seed provider, or crop consultant to determine the pollination needs of the crop and your variety – including information on compatibility for varieties that need cross-pollination, field or orchard set up, and hive stocking rates and placement.

Сгор	Dependence on Pollinators	Attractiveness to pollinators	Honey bee stocking rate/acre	Fruit Set Goal	
Almond	great	high	1-4 (average = 2.5)	60%	
Apple	great	high	1-5 (average = 1.5)	2-8%	
Apricot	essential	high	1-2	20-25%	
Highbush Blueberry	great	low for honey bees	2-4 (average = 3)	over 80%	
Peach	great	high	none	15-20%	
Pear	essential	low for honey bees	4-5	3-11%	
European Plum	essential	high	2	15-20%	
Tart Cherry	great	high	0-2 (average = 1)	over 80%	
Sweet Cherry	great	high	1-5 (average = 1.7)	over 60%	
Pumpkin	essential	high (morning)	0-3 (average = 1.5)	Flowers only open in the morning	
Raspberry	great	high	0.2-1 (average = 0.8)	60-100%	
Watermelon (fresh market)	essential	high (morning)	0.2-5 (average = 1.8)	Flowers only receptive in the morning	

Honey bee stocking rates and pollination dependencies based on Delaplane, K.S., D.R. Mayer, and D.F. Mayer. 2000. Crop Pollination by Bees. CABI, Klein et al. 2007. Importance of pollinators for changing landscapes in world crops. Proc Biol Sci. 274:1608, and Temperate-Zone Pomology by Melvin Neil Westwood, 3rd edition. 1993 by Timber Press, Inc. Portland, OR. pg 247.

Appendix 3 SAMPLE DATA SHEET TO MONITOR CROP POLLINATION

Crop Pollinator Data Sheet

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Field name:	_Crop/Cultivar:	Year:		
Honey bee stocking rate:	Avg. hive streng	th (number of frames/hive):		
(to learn how to measure hive strength go to this Oregon State document: <u>http://bit.ly/2g0pV8B</u>)				
Date honey bees placed in field: Date honey bees removed from field:				
Date at 5% bloom:	Date at peak bloom	: Date end bloom:		
Track number of good pollination days this year (e.g. temp > 60°F, wind < 10mph, no rain): e.g. ## /				

INSTRUCTIONS: Visit your crop field or orchard **three times**, one of which is during peak bloom, **when weather conditions are good** (e.g. temperature is over 60F, wind is below 10mph, and it's sunny enough that you can see your shadow.) Each time you visit the crop, pick a row in the middle of the block walk in ~50ft (16m) from the field edge and count all of the bees you see visiting your crop flowers for 10 minutes. Only count bees touching the open end of the flower. During this time slowly walk about 150 feet (50m) down the crop row. Avoid counting the same bee twice.

Date sampled (peak bloom)	Number of honey	Number of	Notes	
	bees working	non-honey bees		
	flowers	working flowers		
	X	* *		
Visit 1				
Date//				
Person's name sampling:				
Visit 2				
Date//				
Person's name sampling:				
Visit 3				
Date//				
Person's name sampling:				
Total bees				
Average of all bees/10 min				



Appendix 4

SUMMARY OF RESULTS FROM NATIONAL GROWER SURVEY ON POLLINATION PERCEPTIONS AND PRACTICES

BY KELLY GARBACH, POINT BLUE CONSERVATION SCIENCE

Many specialty crops, like apples, cherries, berries and almonds, depend on pollination to produce marketable fruit and nuts. Most growers rent or own honey bees to ensure they get optimal pollination, but some also use alternative managed bees like managed bumble bees and blue orchard bees (BOBs). In addition, many growers, whether they know it or not, also have wild bees pollinating their crops. Using managed pollinator species in combination with farm management practices that support, augment, and protect pollinator populations to provide reliable and economical pollination of crops is a management strategy called Integrated Crop Pollination (ICP). To many growers, ICP is a relatively new strategy.

In 2015, we surveyed more than 1,400 specialty crop growers in California, Florida, Michigan and Oregon to better understand the pollination priorities and information sources they used. Our grower survey investigated the perceived benefits and challenges associated with "pollinator friendly" management practices. In addition, we asked growers about their adoption and use of these practices.

The majority of growers surveyed used managed honey bees for crop pollination, but stocking rate varied depending on the crop and state (Table 1).

Table 1. Stocking rate for honey bee hives per acre by state and crop. Data reflect the 2014 growing season, reporting number of hives per acre. Price per hive was also variable, ranging from a high of $$154.73 (\pm 1.71)$ in California Almonds to a low of $$31.52 (\pm 6.13)$ in Oregon apples.

	California		Florida		Michigan		Oregon	
	Hives/acre	Cost	Hives/acre	Cost	Hives/acre	Cost	Hives/acre	Cost
Almonds	2	\$154.73 (± 1.71)						
Apples					0.9	\$53.70 (± 5.10)	1.1	\$31.52 (± 6.13)
Blueberries			1.9	\$41.12 (± 8.40)	2	\$52.30 (± 1.30)	3	\$37.99 (± 3.17)



Across the four states and fruit and almond crops, growers' most important goal for crop pollination was achieving consistent, reliable crop pollination. However, "diversity of pollinators" was, consistently, the lowest priority, despite evidence that additional pollinator species increases yield regardless of whether honey bees are present or not.

Growers also reported accessing information about crop pollination from a variety of sources. Personal relationships were ranked as most important for information on pollinator management, including observing their own and neighbors' farms. University Extension, beekeepers and pest control advisers were also listed as an important information sources.

We found that growers' personal experience with potential benefits and concerns related to using ICP practices (e.g. habitat augmentation, combined use of different pollinator species). For example, growers that reported higher potential benefits of ICP were more likely to use ICP practices. Similarly, growers that rated potential concerns highly were less likely to use ICP practices. Researchers and growers continue to assess the potential benefits and concerns associated with different farm management designed to benefit pollinators and enhance crop pollination.

To learn more about survey results in specific regions or for specific crops visit http://icpbees.org/ category/project-icp-extension/

Appendix 5 Additional resources

INTEGRATED CROP POLLINATION

- About Integrated Crop Pollination (Project ICP) https://icpbees.org/
- Infographic: 4 Ways to Help Bees Help You (Project ICP) http://icpbees.org/wp-content/uploads/2014/05/4-ways-to-help-bees_final.pdf
- Pollination Mapper: an On-line Pollination Management Tool (Project ICP)
 pollinationmapper.org
- ICP Youtube channel (Project ICP) https://www.youtube.com/channel/UCN0Z_G59MEi7IW4e1IfvkgA
- Scientific review of Integrated Crop Pollination (Project ICP) http://www.sciencedirect.com/science/article/pii/S1439179116301761

MONITORING POLLINATION

- Guide to monitoring northeast apple pollinators (Cornell University)
 http://www.northeastpollinatorpartnership.org/count-bees/
- Guide to measuring watermelon pollination (UC Davis, Rutgers, and Xerces Society)
 http://xerces.org/assessing-watermelon-pollination/
- Detailed guide to crop pollination, including honey bee stocking rates, from 1976 (USDA) https://www.ars.usda.gov/ARSUserFiles/20220500/OnlinePollinationHandbook.pdf

HONEY BEES

- Evaluating honey bees for pollination (Oregon State University) http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/19777/pnw623.pdf
- Sample Pollination Contract (UF/IFAS) http://edis.ifas.ufl.edu/aa169
- Delaplane, K.S. and D.F. Mayer. Crop Pollination by Bees. CABI publishing. NY, NY

ALTERNATIVE MANAGED BEES

- Managing Alternative Pollinators (Xerces Society)
 http://www.sare.org/Learning-Center/Books/Managing-Alternative-Pollinators
- How to Manage the Blue Orchard Bee (USDA-SARE) http://www.sare.org/Learning-Center/Books/How-to-Manage-the-Blue-Orchard-Bee

WILD POLLINATORS

- Conserving Native Bees on Farmland (MSU Extension) http://nativeplants.msu.edu/uploads/files/E2985ConservingNativeBees.pdf
- Building and Managing Bee Hotels for Wild Bees (MSU Extension) http://icpbees.org/wp-content/uploads/2014/05/Brokaw-and-Isaacs-E-3337-final-PDF-for-printing.pdf
- Wild Pollinators of Eastern Apple Orchards and How to Conserve Them (Northeastern IPM Center) http://www.northeastipm.org/about-us/publications/ipm-insights/ipm-resource-wild-pollinators-ofeastern-apple-orchards-and-how-to-conserve-them/
- Pollinator Conservation Resource Center (UC Davis, Xerces Society) http://www.xerces.org/pollinator-resource-center/

HABITAT FOR POLLINATORS ON FARMS

- Establishing Wildflower Habitat to Support Pollinators of Michigan Fruit Crops http://msue.anr.msu.edu/uploads/resources/pdfs/Establishing_Wildflower_Habitat_to_Support_ Pollinators_of_Michigan_Fruit_Crops_-_E3360.pdf
- Establishing Wildflower Habitat to Support Pollinators of California Row Crops http://icpbees.org/wp-content/uploads/2014/05/CA-Row-Crops-Habitat-Guide-FINAL.pdf
- Decision Trees: Flowering Resources for Pollinators, Existing Natural Areas, and Pesticide Risk Mitigation http://icpbees.org/wp-content/uploads/2014/05/Pollinator-habitat-decision-trees-Final.pdf
- Attracting Beneficial Insects with Native Flowering Plants (MSU Extension) http://nativeplants.msu.edu/uploads/files/E2973.pdf
- Farming for Bees: Guidelines for Providing Native Bee Habitat on Farms (Xerces Society) http://www.xerces.org/wp-content/uploads/2008/11/farming_for_bees_guidelines_xerces_society.pdf
- Using 2014 Farm Bill Programs for Pollinator Habitat (USDA-NRCS, Xerces Society) http://directives.sc.egov.usda.gov/opennonwebcontent.aspx?content=38006.wba
- Regional Pollinator Habitat Installation Guides (Xerces Society) http://www.xerces.org/pollinator-conservation/agriculture/pollinator-habitat-installation-guides/
- Pollinator Habitat Assessment Guides (Xerces Society) http://xerces.org/pollinator-conservation/habitat-assessment-guides/

PROTECTING BEES FROM PESTICIDES

- Minimizing Pesticide Risk to Bees in Fruit Crops (MSU Extension) http://msue.anr.msu.edu/resources/minimizing_pesticide_risk_to_bees_in_fruit_crops
- How to Reduce Bee Poisoning from Pesticides (OSU Extension) https://catalog.extension.oregonstate.edu/files/project/pdf/pnw591.pdf
- Protecting Honeybees from Pesticides (UF/IFAS Extension) http://edis.ifas.ufl.edu/in1027
- Guidance to Protect Habitat from Pesticide Contamination (Xerces Society) http://www.xerces.org/wp-content/uploads/2016/10/ ProtectingHabitatFromPesticideContamination_oct2016-02.pdf
- Biddinger, DJ and EG Rajotte. 2015. Integrated pest and pollinator management adding a new dimension to an accepted paradigm. Current Opinion in Insect Science. 10:204-209 http://ento.psu.edu/pollinators/publications/integrated-pest-and-pollinatormanagement-2014-adding-a-new-dimension-to-an-accepted-paradigm



This striped sweat bee, *Halictus rubicundus*, is one of many ground-nesting bees found in North America. Photo by Jason Gibbs, Michigan State University.



Both managed honey bees, like the one at the edge of this flower, and wild bees, like the squash bee (*Peponapis pruinosa*) drinking nectar at the base of this flower, are important pollinators of pumpkins and squashes. Photo by Katharina Ullmann, The Xerces Society.



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