

Pollinators in Forests – An Annotated Bibliography

This annotated bibliography was compiled while researching pollinators in the woods and other related topics. Some text was copied directly from the source when it was appropriately concise. The document is broken into 9 categories: Forest Pollinator Biology, Phenology, Habitat; Forest Pollinators and Woody Material; Forest Management and Pollinators; Forest Pollinators and Agriculture; Forest Pollinators and Habitat Fragments; Forest Pollinators and Adjacent Land Use; Forest Pollinators and Invasive Plants; Pollinator Research Methodology; and Miscellaneous, for papers that do not fit a specific category but that contain relevant information.

Forest Pollinator Biology, Phenology, Habitat

1. *Adamson, Nancy Lee, et al. "Pollinator Plants: Great Lakes Region," Xerces Society for Invertebrate Conservation, 2017.*

Includes a list of plants beneficial to pollinators native to the Great Lakes region, which includes land in Ontario, Minnesota, Wisconsin, Ohio, Michigan, Pennsylvania, and New York.

2. *Adamson, Nancy Lee, et al. "Pollinator Plants: Northeast Region," Xerces Society for Invertebrate Conservation, 2015.*

Includes a list of plants beneficial to pollinators native to the Northeast Region, which encompasses southern Quebec, New Brunswick, Nova Scotia, the New England states, and eastern New York.

3. *Black, Scott Hoffman, et al. "Pollinators in Natural Areas: A Primer on Habitat Management," Xerces Society for Invertebrate Conservation.*

By aiding in wildland food production, helping with nutrient cycling, and as direct prey, pollinators are important in wildlife food webs. Summerville and Crist (2002) found that forest moths play important functional roles as selective herbivores, pollinators, detritivores, and prey for migratory songbirds. Belfrage et al. (2005) demonstrated that butterfly diversity was a good predictor of bird abundance and diversity, apparently due to a shared requirement for a complex plant community. Habitat needs of native pollinators can be divided into two main categories: a diversity of native flowers available throughout the season, and egg-laying or nesting sites. Pollinators need a diverse community of native flowers. The majority of bee species nest in the ground, digging narrow tunnels that lead to a small number of brood cells. Most of the remaining bee species occupy existing tunnels in large, dead, woody vegetation, though some do chew out the center of pithy twigs (Michener 2000). Bumble bees and honey bees are the main exception to this. Bumble bees require a small cavity such as an abandoned rodent nest for their colony (Kearns & Thomson 2001), and feral honey bees usually occupy large cavities, such as a hollow tree (O'Toole & Raw 1999). Some wood-nesting species also need materials such as mud, leaf parts, or tree resin to construct brood cells in their nests (O'Toole & Raw 1999). It is also important that nest sites are close enough to sources of nectar and pollen (Cane 2011). Specialist species and their needs should also be taken into consideration, as these general guidelines are aimed at promoting generalist species. Also discusses the impacts of grazing, fire, mowing, herbicides, and insecticides.

4. Dibble, Alison C., et al. 2018, "Bees and Their Habitats in Four New England States," umaine.edu/mafes/wp-content/uploads/sites/98/2018/07/Bees-and-Their-Habitats-in-Four-New-England-States.pdf#:~:text=Four%20states%20contain%20over%20401,back%20as%20of%20the%201870s.

A look at bees in Maine, Massachusetts, New Hampshire, and Vermont (abbrev. NNE). These states had their forests cleared in colonial times, which have now been growing back since the 1870s. An estimated 15% of bees in these states visit only one or a few plant taxa. The report lists 15 bee habitats with natural and anthropogenic features and suggests 40 plant taxa that may be effective in plantings for bees. Bee habitat consists of the type and abundance of food resources, nest sites, and overwintering habitat. These elements are often patchily distributed through a landscape and might be compromised by changes, such as forest succession, that lead to closed canopy shade conditions, or climate change-related patterns that lead to increased number of rainy days in spring during which bees are unlikely to fly. Timing of the emergence of ground nesting bees is temperature-related, whereas flowering of bee host plants probably has more to do with day length, creating concerns of a lack of synchrony of bee and plant phenology as a result of climate change. Kerr et al. (2015) found that bumble bees in Europe and North America are retreating from the southern extremes of their ranges, but not expanding northward, with no clear reason why, although some bumble bee populations are moving upslope in response to climate warming. Honey bees have had three genetic bottleneck events – introduction of honey bees to the New World, in response to the introduction of parasitic mites, and upon consolidation of bee breeders). Feral honey bee colonies are put at risk by pathogens, arthropods like tracheal mites, indirect arthropod pests like wax moths, and starvation during long cold winters. Also includes some information on parasitic bees and their vulnerability (although these bees are not considered good pollinators if pollinators at all), pests and pathogens, micro-parasites or disease-causing pathogens, and macro-parasites. The majority of NNE plants are thought to be not wholly dependent on any one or a few bee species. In ME, wild bees (not including bumble bees) were more abundant on a diverse mix of mostly native wildflowers, while honey bees and bumble bees were more abundant on non-native clovers, especially yellow sweet clover (*Melilotus officinalis*). Some native cultivars may be comparable substitutions for native species in pollinator habitat restoration projects, but each cultivar should be evaluated on an individual basis. Many native species of trees and shrubs of NNE have particular importance to bees because they offer an abundant floral resource, perhaps at a time when flowers otherwise are scarce. Plants and the pollinators that visit them are discussed in specific detail. Later-season floral resources could be in short supply in NNE due to mowing, and this represents a form of habitat loss. Discusses native vs invasive plants, crops as habitat, and crop-associated habitat. Multiple mass flowering crops blooming in sequence within a landscape mitigate the pre/post-bloom dearth of resources often seen in agroecosystems that contain only a single mass flowering crop. Heterogenous landscapes, where crops with complementary synchronous bloom phenologies are proximal to each other and within a matrix of natural habitat, could help balance effects of extreme floral abundance and can support wild bees. Includes a section on economics of managing bees and their habitats, mostly in regard to crop pollination, but also in costs associated with improving pollinator habitat. Recommends Ward et al. (2014) and Droege (2015) as resources for information on methods to monitor bee abundance. Also identifies gaps in knowledge where further research would be helpful, presented in two tiers.

5. Dumroese, R. Kasten, and Tara Luna. "Growing and Marketing Woody Species To Support Pollinators: An Emerging Opportunity for Forest, Conservation, and Native Plant Nurseries in the Northeastern United States." *Tree Planters' Notes*, vol. 59, no. 2, 2016, pp. 49-60.

Discusses plants that benefit all pollinators but focuses on Lepidoptera due to the potential commercial value for nurseries. There are 4 taxonomic orders of pollinators: coleoptera (beetles), diptera (flies), hymenoptera (bees and wasps), and lepidoptera (butterflies and moths). Butterflies tend to be less effective pollinators than bees – they have smooth bodies, long legs, and are seeking nectar not pollen, although some moths and flowers have an obligate pollination strategy. When herbaceous and woody plants were compared, woody species supported 10 times more lepidopteran species. Lepidopterans use native woody species as larval food sources, for shelter

during larval development, and for pupation, and adults use trees, shrubs, and forbs as nectar sources. Native wetland- and riparian-dependent Salicaceae species serve as larval hosts for many lepidopterans, including those that are largely found only in wetland habitats. Includes an extensive table (Table 2) of woody plants, their form, their floral phenology and pollinators, and the lepidopteran larvae they host. Many common, native woody Rosaceae shrub general are crucial for native bees and lepidoptera. Species highlighted by the authors include native cherries, *Rubus* L., *Rosa* L., *Spiraea alba*, and *Amelanchier alnifolia* (Nutt.). Noted Ericaceae species include *Vaccinium*, *Rhododendron* L., and *Gaylussacia*. The authors also indicate some native woody vine species that support pollinators and mention that shrub layers that benefit pollinators can be appealing for attracting migratory songbirds that feed on the pollinators. The authors include marketing advice for plant nurseries, centered around the appeal of lepidopteran pollinators.

6. "Empire State Native Pollinator Survey." *The New York Natural Heritage Program*, www.nynhp.org/pollinators.

Describes in-progress survey of native pollinators in New York State. Identifies both extensive survey focal taxa and targeted survey focal taxa:

Extensive Survey Focal Taxa

Hymenoptera

Bumble bees and long-horned bees, Family Apidae: *Bombus*, *Melissodes*

Mining bees, Family Andrenidae: *Andrena*, *Calliopsis*

Leafcutter bees, Family Megachilidae: *Megachile*, *Osmia*

Diptera

Bee flies, Family Bombyliidae: *Bombylius*

Saproxylic (decaying wood) hover flies, Family Syrphidae: ~80 species in two subfamilies

Coleoptera

Flower longhorn beetles, Family Cerambycidae: *Lepturinae*

Hairy flower scarabs, Family Scarabeidae: *Trichiotinus*

Lepidoptera

Hawk (sphinx) moths, Family Sphingidae: 26 species that feed as adults

Flower moths, Family Noctuidae: *Schinia*

Targeted Survey Focal Taxa

Hymenoptera

Bumble bees of known or potential conservation need, *Bombus affinis*, *B. terricola*, *B. pensylvanicus*, *B. fervidus*, *B. auricomus*, *B. borealis*, *B. ashtoni*, *B. insularis*, *B. fernaldae*

Oil bees, *Macropis*, *Melitta*

A cuckoo bee, *Epeoloides pilosula*

Diptera

Saproxylic (decaying wood) hover flies, Family Syrphidae: ~80 species in two subfamilies

Eastern long-nosed fly, *Cynorhinella longinasus*

Golden pine fly, *Callicera erratica*

Lepidoptera

Slender flower moth *Schinia bifascia*, golden aster flower moth, *S. tuberculum*

Monarch, *Danaus plexippus*

Additional butterflies of known or potential conservation need

7. Grundel, Ralph, et al. "Floral and Nesting Resources, Habitat Structure, and Fire Influence Bee Distribution across an Open-Forest Gradient." *Ecological Applications*, vol. 20, no. 6, Sept. 2010, pp. 1678–1692., doi:10.1890/08-1792.1.

Examined how plant community composition, plant diversity, nesting suitability, canopy cover, land use, and fire history affected bee distribution across an open-forest gradient in northwest Indiana. Plant community composition was not a comparatively significant predictor of bee community composition. Bee abundance was negatively related to canopy cover and positively to recent fire frequency. Bee richness was positively related to plant richness and abundance of potential nesting resources. Bee community composition was significantly related to plant richness, soil characteristics potentially related to nesting suitability, and canopy cover. In summary, bee abundance was predicted by a different set of environmental characteristics than was bee species richness, and bee community composition was predicted, in large part, by a combination of the significant predictors of bee abundance and richness. Differences in bee community composition along the woody vegetation gradient were correlated with relative abundance of oligolectic bees. Because oligolectes were rarer than diet generalists and were associated with open habitats, their populations may be especially affected by degradation of open habitats. More habitat-specialist bees were documented for open and forest/scrub habitats than for savanna/woodland habitats, consistent with bees responding to habitats of intermediate woody vegetation density as ecotones rather than as distinct habitat types. Nestedness analysis indicated that species composition in species-poor sites was not merely a subset of species composition at richer sites. The lack of significant effects of proximity (of sites) or nestedness suggests that factors at a small spatial scale strongly influence bees' use of sites. Overall, the findings indicated that patterns of plant diversity, nesting resource availability, recent fire, and habitat shading, present at the scale of a few hundred meters, are key determinants of bee community patterns in the mosaic open-savanna-forest landscape. Used bowl trapping and netting. Found that 11% of bee species visiting open sites were oligolectes compared to 2% of forest bee species, indicating that open habitat bee species were more likely to have relatively narrow diets. Bee richness increased as availability of dead woody vegetation increased.

8. Hahn, Melanie, and Carsten A. Brühl. "The Secret Pollinators: an Overview of Moth Pollination with a Focus on Europe and North America." *Arthropod-Plant Interactions*, vol. 10, 25 Jan. 2016, pp. 21–28., doi:10.1007/s11829-016-9414-3.

Review of literature to identify plant and moth species connected via pollination interactions. Most of the interactions could be attributed to the moth families Noctuidae and Sphingidae, and to the plant families Orchidaceae and Caryophyllaceae. The review only considers studies in which a moth-flower interaction resulted in a pollen load on the moth body, pollen deposition during a flower visit, or seed production after a flower visit. Certain orchids are highly specialized for pollination by moths – orchid pollen is often presented in pollinia, which can attach to specific positions on the bodies of visiting moths, allowing them to carry the pollen of different orchid species without causing hybridization. It also allows identification of visited orchid species that weren't observed. Moth pollination in ecosystems is characterized by high temporal variability – in visitation and pollen loads. Light trapping may produce biased results because the degree of light attraction varies between moth species, and light traps can attract moths before they have visited flowers and come in contact with pollen grains, which can lead to reduced pollen presence rates. The importance of moths in agricultural landscapes is most likely related to their pollination of non-crop plants, which maintains biodiversity in agro-ecosystems.

9. Herrera, Carlos M. "Thermal Biology and Foraging Responses of Insect Pollinators to the Forest Floor Irradiance Mosaic." *Oikos*, vol. 78, no. 3, Apr. 1997, pp. 601–611., doi:10.2307/3545623.

59% of pollinator species in the study preferentially selected plants based on mean irradiance at capture point (MICP) – dipterans tended to be restricted to areas of relatively low irradiance, hymenopterans foraged over the entire irradiance gradient. MICP was inversely related to body size, with the relationship mediated by correlations between body size and thermal biology parameters. Insect pollinators visiting the plant species studied were netted systematically from dawn to dusk and measured for thoracic temperature within 5 seconds of capture with a fast-response needle microprobe. Air temperature and solar irradiance were also measured at all capture points within 1 minute of netting. The forest understory study site was characterized by a bimodal distribution of irradiance levels, and irradiance-biased pollinator foraging could impact plants exposed to different pollinator assemblages based on where in the understory they are located.

10. Jordan, Sarah Foltz, et al. "Habitat Assessment Guide for Pollinators in Yards, Gardens, and Parks," *Xerces Society for Invertebrate Conservation*, 2019.

A tool to evaluate pollinator habitat at a given site, and identify areas for improvement, as well as prioritize next steps. Includes a checklist of actions to promote foraging resources, protect pollinators from pesticide exposure, promote nesting and overwintering habitat, and contribute to pollinator conservation in the community.

11. Jordan, Sarah Foltz, et al. "Pollinator Habitat: Natural Areas and Rangelands Assessment Form & Guide," *Xerces Society for Invertebrate Conservation*, 2014.

Habitat assessment form with a scoring sheet for natural areas and their suitability for pollinator habitat.

12. Motten, Alexander F. "Pollination Ecology of the Spring Wildflower Community of a Temperate Deciduous Forest." *Ecological Monographs*, vol. 56, no. 1, 1986, pp. 21–42., doi:10.2307/2937269.

A long paper that addresses many topics such as pollinator effectiveness, pollinator visitation rates, pollination success, plant pollination and reproduction strategies, other constraints on fecundity, and pollination competition. Spring wildflower communities of the mesic deciduous forest studied are usually adequately pollinated in spite of a short blooming season, considerable overlap in flowering times, extensive pollinator sharing by concurrently blooming species, and inclement weather that frequently interrupts insect activity. Pollination-limited reproductive success was evident only in species pollinated primarily by queen bumble bees, most of which were also self-incompatible. Competition for pollination among wildflower species may act with other causes of insufficient pollination as a selective force to maintain a characteristic set of floral biology traits within the community. Insect visitors to flowers were individually captured and killed, and bees emerging early in the spring when few flowers were open were collected in pan traps. Visitation rates were calculated in units of visits per flower per hour, and the most abundant visitor was the bee fly *Bombylius major*. Most individual floral visitors foraged on more than one host. The time of greatest risk of insufficient pollination varied from one species to another.

13. "Nesting Resources." Xerces Society, xerces.org/pollinator-conservation/nesting-resources.

70% of native bees are ground nesting, creating burrows in soil. Some ground nesting bees are amongst the earliest to emerge in the spring, making them vital pollinators of cherries, plums, and other tree fruits. Another example are the squash bees (*Peponapis* and *Xenoglossa*) which nest in the soil where pumpkins and other cucurbit crops are grown and are specialist pollinators of those vegetables. They need access to bare soil and may be impacted by tilling. 30% of native bees are cavity nesting such as leafcutter and mason bees. These species need cavities in dead wood, hollow stems, or brush piles. Where possible, allow dead trees or snags to remain in the landscape or incorporate this material into habitat areas. Bumble bees create nests in cavities underground or in trees. They prefer abandoned rodent burrows or sheltered areas such as those beneath brush piles. Bumble bees generally do not nest in the same location repeatedly unless by chance. After queens have reared their young throughout the spring and summer, they die and newly mated queens abandon the nest and hibernate over the winter beneath leaf litter or at the base of bunch grasses or in other sheltered locations. To benefit bumble bees, consider maintaining a small pile of brush such as hedge clippings and woody plant material. This will provide cover for wildlife that will in turn create nesting habitat for bumble bees. 2/3 of host plants for butterflies and moths are trees and shrubs. One oak tree for example can support more than 500 species of butterflies and moths.

14. *New England Pollinator Handbook*, USDA Natural Resources Conservation Service, 2009.

Long document, provides information on how to plan for, protect, and create habitat for pollinators in agricultural settings. Table of contents includes sections on pollinator nesting and overwintering sites; minimizing pesticide use as well as the impact of mowing, haying, burning, or grazing; protecting ground and tunnel nesting bees; protecting honey bees; and enhancing and developing new pollinator habitat. Lots of good, but similar information to other documents, so not including a full summary here. Includes woody plant, herbaceous plant, and pollinator lists. Plant lists are limited to those plants thought to require insect pollination and to be relatively widespread and commonly found in the public marketplace as seed or nursery stock – many other plants are also good for bees.

15. "Pollinator-Friendly Plants for the Northeast United States," USDA Natural Resources Conservation Service.

Includes information on 57 pollinator-friendly plant species, and describes their pollinator value, bloom time, flower color, height, wetland indicator, light requirements, habitat, soil moisture, and which beneficial insects it is valuable to. Also includes a page on resources for information on plants and pollinators, and one for native plant suppliers.

16. "Trees for Bees and Other Pollinators," Arbor Day Foundation, Apr. 2015, www.arborday.org/trees/health/pests/article-trees-for-bees.cfm.

Lists "bee-friendly" trees and says that "many additional trees are also good sources of food for pollinators." Trees listed: Maples, *Acer* sp.; Serviceberry, *Amelanchier* sp.; Koelreuteria, *Koelreuteria* sp.; Fruit trees; Crapemyrtle, *Lagerstroemia* sp.; Liquidambar, *Liquidambar* sp.; Black tupelo, *Nyssa sylvatica*; Sourwood, *Oxydendrum arboreum*; Black Locust, *Robinia pseudoacacia*; Linden, *Tilia* sp.. Other trees that provide food for pollinators include hawthorns (*Crataegus* sp.), tuliptrees (*Liriodendron tulipifera*), southern magnolias (*Magnolia grandiflora*), privets (*Ligustrum*), and many additional natives.

**although some are, not all these trees are native to upstate NY

17. Ulyshen, Michael D., et al. "On the Vertical Distribution of Bees in a Temperate Deciduous Forest." *Insect Conservation and Diversity*, vol. 3, 2010, pp. 222–228., doi:10.1111/j.1752-4598.2010.00092.x.

Bees were sampled using flight-intercept traps suspended in the canopy and near the ground in a bottomland hardwood forest in the southeastern United States. Bee abundance, richness, and Shannon's diversity were considerably higher in the canopy than near the ground. The authors concluded that the bee community in the canopy was distinct from that near the ground. There was a pattern of more abundance in the canopy than near the ground in mid-to-late summer, a period coinciding with low floral resource availability. The authors suspect that bees frequent the canopy, particularly during times of low nectar and pollen availability, to acquire non-floral resources such as honeydew and sap. The traps used were two clear plastic vanes in a cross shape attached to white buckets with propylene glycol added to kill and preserve specimens. The buckets had a hole with fine mesh to allow excess rainwater to drain out. The traps were suspended from branches in the canopy to be hanging above the lowest leaf-bearing branch in each tree. *Augochlora pura* (Say) accounted for over 91% of all bees collected and was over 40 times more abundant on average in the canopy than near the ground – when the data from this species was removed, however, the remaining species still showed similar data patterns. Bees were highly active in the canopy throughout the season, even when trees were not producing nectar or pollen. Certain cavity- and wood-nesting bee species may preferentially or occasionally rest in the canopy. All four bee species found to be significantly associated with the canopy in this study have been observed feeding on honeydew, which although less nutritious than floral nectar, is readily available in the canopy throughout the season. 14 bee species were collected only near the ground, but only 2 species significantly.

18. "Who Are the Pollinators?" Xerces Society, <https://xerces.org/pollinator-conservation/about-pollinators>

Helpful webpage from the Xerces Society with information about types of pollinators – solitary bees, bumble bees, wasps, flies, butterflies and moths, beetles.

Pollinators and Woody Material

19. McCavour, Melanie J., et al. "The Role of Aggregated Forest Harvest Residue in Soil Fertility, Plant Growth, and Pollination Services." *Soil Science Society of America Journal*, vol. 78, 18 Aug. 2014, pp. S196–S207., doi:10.2136/sssaj2013.08.0373nafsc.

Plant size (measured in basal area or leaves per square meter) was shown to increase as distance from slash piles decreased. Cherry trees were shown to have larger leaves farther from piles, which is a typical response to shade. Soluble organic compounds decreased as a negative exponential function with distance from slash piles. Pin cherry trees and white spruce growing near slash piles had greater stem size, flowers per plant, and foliar P, and strawberry and raspberry plants had higher flower and fruit abundance closer to slash piles as well. The effect of distance on cherry growth rate differed temporally, with trees close to piles having an advantage in some years and a disadvantage in others. The authors concluded that in industrial forests, piles replace canopy gaps as sites where understory plant species can episodically reproduce, and in contrast to canopy gaps represent a long-term source of elevated soil nutrients. They release nutrients more slowly and enhance available light by locally delaying canopy closure of the planted species. Soil and plant attributes were assessed on transects radiating from slash piles using resin bags placed in the soil, foliar samples, and assessments of growth and reproductive output. Soil moisture content was not shown to be correlated with distance, and plant attribute responses were more strongly correlated with distance than soil nutrition alone. Similar findings resulted from study in an older plantation, with some variation in strength of relationships. The authors also

mentioned some of the limitations of comparing data between studies due to methodological differences, and referenced other literature citing different effects of aggregating slash on non-crop species.

20. Rodríguez, Antonio, and Jari Kouki. "Emulating Natural Disturbance in Forest Management Enhances Pollination Services for Dominant *Vaccinium* Shrubs in Boreal Pine-Dominated Forests." *Forest Ecology and Management*, vol. 350, 15 Aug. 2015, pp. 1–12., doi:10.1016/j.foreco.2015.04.029.

The authors assessed how two methods aimed to promote biodiversity – prescribed fire and retention forestry (RET) – affect ecosystem services supported by bilberry and lingonberry in Scots pine-dominated boreal forests. Shrub cover, flowering, berry yield, and percent fruit set of both shrubs were measured and bees were sampled by pan-traps on 24 study sites. In general, bilberry performance and reproduction were higher at uncut sites, while lingonberry flowering was positively affected by fire and retention. Bee community composition was mainly determined by percentage of bare ground and number of logs within sites, both nesting resources largely determined by fire and retention. Burnt sites with retention trees serve as pollinator source habitats and contain floral resources. Open areas with dead wood created after fire provide suitable areas for post-disturbance recovery and recolonization of dwarf shrubs, and attract large quantities of flower-visiting insects, offering them higher temperatures plus flowering and nesting resources. Bumblebees were relatively independent of local nesting resources in comparison with solitary bees. There was a positive relationship between the number of CWD (coarse woody debris) logs and bee species richness for both shrubs after controlling for bee abundance effects.

21. United States, National Agroforestry Center. "Enhancing Nest Sites For Native Bee Crop Pollinators," 2007. *Agroforestry Notes*.

Most solitary bees are active as adults for only a few weeks each year and most have only a single annual generation, excepting some social sweat bees that can have several overlapping generations through the summer. Solitary wood nesting bees – some build nests in the soft pithy centers of some twigs (e.g. box elder, elderberry, various cane berries), some inhabit tunnels left by wood-boring beetle larvae, carpenter bees excavate their own tunnels, and another small set of bee species tunnel into soft, above-ground rotting logs and stumps. Most of our native bee species excavate their nests underground, and need direct access to the soil surface, often on sloped or well-drained sites. Bumble bees construct nest in small cavities, often in old rodent burrows, either underground or beneath fallen plant matter, or occasionally aboveground in abandoned bird nests. To protect potential nesting areas, the authors suggest retaining dead or dying trees and branches whenever it is safe and practical, along with rotting logs; protecting sloped or well-drained ground sites where plants are sparse and direct access to soil is available; leaving some areas of the farm untilled and minimize weed control tillage; and protecting grassy thickets, or other areas of dense, low cover from mowing or other disturbance. They also recommend more active management, like planting shrubs or other plants with pithy stems and annually cutting back some new growth to expose the stems' pithy interior (elderberry, boxelder, blackberries, raspberries, sumac, dogwood). Bumblebees often occupy the grassy interface between open fields and hedgerows or woods, which has been attributed to the presence of abandoned rodent nests.

22. Urban-Mead, Katherine R., et al. "Bees in the trees: Diverse spring fauna in temperate forest edge canopies." *Forest Ecology and Management*, vol. 482, 2021, doi:10.1016/j.foreco.2020.118903

Describes the vertical stratification of spring bee communities in temperate hardwood deciduous forests and explores associations with bee traits, canopy cover, and coarse woody debris. Bees were sampled using pan

traps in the canopy (20-25 m above ground) and understory (<1m). The canopy had equal species richness to the understory, but higher diversity and a much higher proportion of female bees. Female solitary, social, soil- and wood-nesting bees were all abundant in the canopy while soil-nesting and solitary bees of both sexes dominated the understory. Canopy cover increase (leaf-out) was negatively associated with understory but not canopy bee abundance. Both the canopy and understory were dominated by generalist bees. Recommend management for diversity of tree species, bloom time, and age, and retention of deadwood for nesting habitat. Suggests that canopy-level deadwood may be an important and overlooked resource for wood-nesting bees. Suggests that management for tree species and age class diversity is important for providing continuous resources for a diverse assortment of bees.

23. Westerfelt, Per, et al. "Nesting of solitary wasps and bees in natural and artificial holes in dead wood in young boreal forest stands." *Insect Conservation and Diversity*, vol. 8, 2015, doi: 10.1111/icad.12128

Holes in standing dead wood (SDW; diameter >10cm, height >1m) had higher occupancy of insects than holes in stumps and logs. Retention and creation of SDW objects of different tree species at final felling is recommended. Solitary hole-living aculeate nests typically consist of cells where the female deposits one egg and a supply of food. Species turnover is probably strong along a light gradient, since 'shade tolerance' varies between species. Lying dead wood (LDW) defined as whole trees or tree parts, diameter > 5cm, length >1m. The density of potential nesting holes was similar for SDW and stumps but lower for LDW. Trap nests were preferred over natural dead wood. The observed patterns in occupancy suggested that harder, dryer wood was preferred. Results suggest that dead wood retention, by artificially created high stumps and retained naturally occurring dead standing trees is a positive measure for aculeate nesting. Hole diameter was important for natural holes in dead wood – species tend to prefer holes that are as small as possible to protect against predation or parasitism. The size of the wood object seemed to be less important for aculeate occupancy, than the hole- and wood quality. The importance of LDW was difficult to assess since most surveyed objects were thin and lacked potential nesting holes.

24. Wheeler, Justin. "Bring Back the Pollinators: 5 Ways to Increase Nesting Habitat for Native Bees." *Xerces Society for Invertebrate Conservation*, 17 Mar. 2017, xerces.org/blog/5-ways-to-increase-nesting-habitat-for-bees.

Both ground nesting and cavity nesting bees create a ball from pollen and nectar on which they deposit an egg in a "bee nursery" known as a brood chamber. Ground nesting bees form tunnels in the ground with multiple brood chambers. Cavity nesting bees find an existing tunnel in the form of a hole in dead wood or the hollow stems of certain plants. They create brood chambers starting at the back of the tunnel and working their way to the front, sealing each chamber as they go with mud or bits of plant material. Bumblebee species nest in small colonies where worker bees attend to the nest. They usually build their nest in dry, protected, and hidden cavities below ground, such as an abandoned rodent burrow, under piles of wood or brush, under sheds, or sometimes in old birdhouses. Ground nesting bees are some of the earliest pollinators to emerge in the spring, making them vital to pollination of fruit trees such as cherries, plums, and apricots, as well as other flowering trees, shrubs, and spring ephemerals. Even a 1-inch layer of mulch can be impenetrable to these small bees. The author also recommends growing raspberries and other plants with pithy or hollow stems such as Joe Pye weed (*Eutrochium* spp.), elderberry (*Sambucus* spp.), hydrangea, and others. Cavity nesting bees will make nests in the dried stems and twigs from previous years' growth, so don't aggressively cut back or clean up these plants and consider leaving dead branches alone. Native bunch grasses also provide nesting sites and protection for bumble bee queens to overwinter. The author recommends leaving piles of twigs, branches, or logs in the garden, as the activity of birds feeding on beetles and carpenter ants creates chambers in the wood for cavity nesting bees to

lay their eggs. Small mammals also use brush piles to protect their burrows that bumble bees later use to nest, and brush piles provide cover for other ground nesting bees.

Forest Management and Pollinators

25. Campbell, J. W., et al. "Effects of Prescribed Fire and Fire Surrogates on Floral Visiting Insects of the Blue Ridge Province in North Carolina." *Biological Conservation*, vol. 134, no. 3, 2007, pp. 393–404., doi:10.1016/j.biocon.2006.08.029.

The authors investigated how prescribed burning, mechanical shrub control, and combination of the two affected abundance of floral visiting insects. Hymenoptera was the most abundant and diverse order collected, with Halictidae being the most abundant family. Most floral visitors were captured in the mechanical shrub control plus prescribed burn treatments, and overall species richness was higher on these treatments as well – increased fuel loads on the plots resulted in hotter fires and more tree mortality. Total pollinator abundance and the abundance of most orders and families was correlated with decreased tree basal area and increased percent herbaceous plant cover. Floral visitors increased in abundance and species richness most from forest disturbance that reduced the density of overstory trees and increased the amount of herbaceous plant growth. Fire could affect important pollinators either directly by fire-related mortality or indirectly by limiting flower resources. Nesting resources could also be affected by fires, although Potts et al. (2005) found increased abundance of ground nesting bees in recently burned areas due to increased bare ground available for nesting. For the mechanical treatments (chainsaw felling and sectioning or limbing of the shrub understory), the cut material was left in place. Pollinator collection was done through colored pan and malaise traps and butterfly surveys on transect walks. The authors specifically distinguished that they surveyed "floral visitors" and not pollinators, since they did not measure pollination effectiveness, but use the terms interchangeably. Increased herbaceous vegetation growth and species richness, dead wood, or the greater disturbances and exposure of the mineral soil on mechanical plus burn plots could have provided more food and/or nesting habitat for ants and subsequently their parasites. Forest management that creates and maintains open stands that allow more sunlight to reach the forest floor and provide corridors for movement and dispersal may favor butterfly colonization over time.

26. Hanula, James L., et al. "Conserving Pollinators in North American Forests: A Review." *Natural Areas Journal*, vol. 36, no. 4, 2016, pp. 427–439., doi:10.3375/043.036.0409.

Bees and butterflies generally favor open forest habitats regardless of forest type, geographic region, or methods used to create these habitats. Efforts to improve forest conditions for pollinators should consider the needs of specialist species and vulnerable species with small, scattered populations. The review is organized into 3 main sections: effects of forest management on pollinators, with a focus on thinning/gap creation and prescribed fire; value of roadside and powerline corridors and how best to manage these avenues of open habitat; variable effects of nonnative species on bee and butterfly communities. Butterflies are generally more numerous in non-forested habitats than in forests, and, like bees, benefit from more open forest conditions. Hanula et al. (2015) found that the highest species richness and bee abundance occurred in mature pine forests with open canopies and little shrub cover, which are created and maintained by regular thinning and frequent prescribed burning; high species richness and bee abundance also occurred in recently cleared forests. In that study, forests that provided the best long-term pollinator habitat had high herbaceous ground cover and were being managed as foraging habitat for red-cockaded woodpeckers (an endangered species). Romey et al. (2007) examined the effects of small-scale tree removals from a northern hardwood forest in New York, and found that

the greater the forest cover removed, the higher the bee abundance and diversity in the openings. Korpela et al. (2015) found data that suggest floral resource availability is less crucial to butterflies than to bumblebees, suggesting that butterflies respond more to open and warmer conditions. The authors mention a proposition by Carter and Anderson (1987) to improve forest roads with cutouts alongside and the creation of “corner glades.”

27. Jackson, Michelle M., et al. “Logging Legacies Affect Insect Pollinator Communities in Southern Appalachian Forests.” *Southeastern Naturalist*, vol. 13, no. 2, 2014, pp. 317–336., doi:10.1656/058.013.0213.

The authors investigated how pollinator abundance and community composition varied with distance from logging roads and elevation in old (logged >90 years ago) and young (logged 20-40 years ago) southern Appalachian forests. Insect pollinators were sampled at 15 previously logged sites along an elevation gradient at 5 distances from logging roads during a summer and spring using pan traps (yellow, blue, white). In summer, many pollinator groups were more abundant in younger forests and closer to logging roads, likely due in part to more light availability and a greater abundance of floral resources near roads. Total bee abundance was greater near logging roads, but only in younger forests, suggesting that the role of roads in providing nectar and other resources may diminish as forests mature. In spring, many pollinator families were less abundant at mid-distances from roads compared to road edges, but abundances were generally the same at 100m from the road as at road edges. Apidae and Andrenidae were strongly associated with high elevations in spring. Logging legacies may provide supplemental resources such as food and nesting sites to insect pollinators during the summer months especially. Certain pollinator groups, including some rare endemics and wood-nesting bees show positive associations with forested habitat. Logging might result in optimal habitat for some pollinator groups at first but habitat suitability declines over time as succession proceeds – canopy openness, herb cover, and tree species richness are all highest in very young stands, lowest in mid-aged stands, and increase again in very old stands. The benefits of roads to pollinator abundance appeared to diminish as forests matured and old-growth characteristics (i.e., canopy gaps) were restored. Elevation was less important than logging history and was more variable in its effects on the pollinator community. There was no effect of stand age on overall insect or bee abundance in spring, indicating that habitat conditions in young stands, other than litter depth and forb cover, were also suitable for pollinators. Based on an extensive review, Roulston and Goodell (2011) suggest that floral resource availability is the primary factor influencing wild bee abundance and that little evidence supports nest-site limitation. The effects of elevation were most pronounced in spring (March-April), which is the bloom time for many wildflower species in the region. Two important groups of bee pollinators, Andrenidae and Apidae, were more abundant at high elevations. Bombyliidae declined in abundance with elevation in spring. Forb cover and flower presence increased with elevation, perhaps due to a moisture gradient.

28. Proctor, Eleanor, et al. “Responses of Insect Pollinators and Understory Plants to Silviculture in Northern Hardwood Forests.” *Biodiversity and Conservation*, vol. 21, 24 Mar. 2012, pp. 1703–1740., doi:10.1007/s10531-012-0272-8.

Group-selection silviculture (removal of groups of trees - GSS) is proposed as an alternative to single-tree selection, reducing homogeneity in tree species composition by allowing less shade-tolerant species to grow in gaps. Treatments included “regular” plots with both GSS and single-tree selection, in the regular application of Ontario, “intensive” plots with only GSS in a grid pattern, and control plots with natural canopy gaps identified for comparison. Data was collected on site conditions, soil moisture, plant composition (through surveys), plant fecundity and seed set, and insects (collected with malaise traps). GSS increased the abundance of pollinators and flowering stems, but only after leaf-out. Once leaf-out occurred, more syrphids and bees showed greater

abundances, syrphids had greater species richness, and a greater proportion of *Claytonia caroliniana* ovules were fertilized, suggesting that insect pollinators were more effective in gaps even in the spring. Unlike spring, summer plant communities were more variable across both treatments and locations. *Rubus strigosus* and bees benefitted most from the creation of canopy gaps, and in fact it seems that the presence of flowering raspberry was the primary contributor to the pollinator communities of gaps during the summer. The different harvest techniques did not show an effect on the composition of pollinator communities. The authors noted that pan trapping and netting were inefficient at catching syrphids, but valuable in sampling bees.

29. Summerville, Keith S. "Forest lepidopteran communities are more resilient to shelterwood harvests compared to more intensive logging regimes." *Ecological Applications*, vol. 23, no. 5, 2013, pp. 1101-1112.

Examined whether moth species assemblages returned to pre-logging composition (compositional resilience), species richness (structural resilience), and guild diversity (functional resilience) after forest management. The 4 harvest treatments included: no logging, clear-cutting, shelterwood harvests, and group selection harvests. Results suggest that timber harvest has significantly different impacts on forest lepidopteran communities depending on the amount of timber removed. In general, moth communities in stands that were managed with shelterwood techniques (~15% standing bole removed) were the most resilient. Additionally, the effects of group selection harvest seem to penetrate beyond the harvest allotment into unlogged stands in the same management unit, suggesting that the complete removal of trees from a managed stand may compromise the broader spatial resilience of the lepidopteran species pool. Herbaceous-feeding Lepidoptera appear to quickly colonize stands managed with group selection or clear-cutting, potentially biasing species richness measures under these management strategies. Woody-plant-feeding moth species seem resilient to shelterwood logging with low biomass removal, although changes in species richness of herbaceous-feeding species displayed the opposite pattern. Moth communities in stands managed with group selection were dominated by generalist species. There are also potential differences between microlepidoptera and macrolepidoptera unexplored by this study, and less-studied nocturnal lepidoptera may have different impacts/be impacted differently. Moths were collected using Universal black light traps.

Forest Pollinators and Agriculture

30. Bailey, Samantha, et al. "Distance from Forest Edge Affects Bee Pollinators in Oilseed Rape Fields." *Ecology and Evolution*, vol. 4, no. 4, 15 Jan. 2014, pp. 370–380., doi:10.1002/ece3.924.

Investigated the specific importance of forest edges in providing potential pollinators in *Brassica napus* fields in two areas in France. Bees were caught with yellow pan traps at increasing distances from both warm and cold forest edges into *B. napus* fields during the blooming period. The authors found that both bee abundance and taxa richness were negatively affected by the distance from forest edge, although responses varied between bee groups and edge orientations. The further away collected bees were from the edge, the larger they were. Bee pollination of *B. napus* leads to improved yields and to a shorter blooming period, thus increasing the crop's market value. The authors categorized plots adjacent to forest edges as "cold orientation" (northern and eastern exposure) and "warm orientation" (southern and western exposure) according to the amount of Celsius degree they received during the day. Forest edges present a complex vertical structure and undisturbed soil offering shelter for all bees and a wide range of nesting sites for both cavity-nesting and ground-nesting bee. The social taxa, *Bombus* spp. And *A. mellifera*, may benefit even more than solitary taxa from the lower competition in the center of the plot because they need to store large amounts of resources to start colonies. The authors found

that forest edge is likely to be a nesting and/or mating site for *Andrenidae*, and a potential foraging site for all bees because of the early spring-flowering trees or forbs it contains.

31. Lee-Mader, Eric, et al. "Cover Cropping for Pollinators and Beneficial Insects," *Sustainable Agriculture Research and Education*.

A farm's ability to support its own pollinator community provides security, especially if managed honey bee hives become scarce or expensive. Honey bees have significant nectar demands and require large-scale flowering habitats to produce surplus honey. Research suggests that diverse pollen and nectar resources may help improve the overall health of bees and increase their chances of detoxifying low doses of some pesticides. Many natural pest enemies also benefit from flowering cover crops. Fast-growing annual cover crop species such as rye and crimson clover are the most common choice for rotation with annual field crops, but in perennial farm systems like orchards and vineyards, longer-term ground cover may be desired. It is critical that insecticides are not over-sprayed and allowed to drift down onto flowering plants in the ground cover. In the CTIC-SARE survey, farmers who plant cover crops identified their top five reasons for doing so as: 1) increase soil organic matter; 2) reduce soil erosion; 3) reduce soil compaction; 4) manage weeds; and 5) provide a nitrogen source. The same survey found that farmers are increasingly likely to try cover crops without any sort of financial assistance. Different conservation needs call for different types of cover crops. Cover crops that support low levels of crop pests may be valuable in some cases, as they can provide a consistent food source for beneficial predators: when the cover crop dies back, these predators move to managing pests on the cash crop. Cover crops should also be adapted to local conditions, and a diverse assortment may be best. The authors gave a successful example in which a farm grew nine crop species and maintained open, un-mowed buffer areas around the farm, resulting in a large abundance of bee species. Mixtures of cover crops, or cocktails, have synergy—they generally work better than each single species could alone. The process of terminating a cover crop can be very detrimental to pollinators and beneficial insects, especially when the cover crop is actively flowering when terminated. Risks to insects include both direct mortality and indirect harm. The authors provide recommendations to reduce the impact of cover crop termination. To mitigate some of the impact of early termination of cover crops required by crop insurance, the authors recommend supplementing cover crops with other pollen and nectar resources such as hedgerows, permanent wildflower meadows, or other high-quality natural areas; and leaving small sections of the field in the cover crop to sustain pollinators in the absence of other forage sources. The authors include tables of detailed data by cover crop species. Less common species of native bees often require more permanent plant communities comprised primarily of native plant species. In general, to maximize the diversity and abundance of beneficial wild insects, flowering cover crops should be combined with the restoration and maintenance of permanent, high-quality, pesticide-free native plant habitat in other areas of the farm. The authors also address insecticide use and its impact on pollinators.

32. Monasterolo, M., et al. "Soybean Crops May Benefit from Forest Pollinators." *Agriculture, Ecosystems & Environment*, vol. 202, 2015, pp. 217–222., doi:10.1016/j.agee.2015.01.012.

The bee species observed on soybean plants were well represented in the forest, and *Apis mellifera* was the most abundant species overall, and the only species recorded visiting soybean flowers at all studied distances from the forest. Wild visitors showed smaller species being restricted to the forest proximity and replaced by larger ones toward the interior of the crop. Total visitation rates were significantly negatively affected by distance to the forest. Pollinator activity was shown to lead to increased soybean yield. Visitation rate was estimated as [(visitor number/open flowers in the patch)/observation time]x1000 and calculated for each

pollinator species in the forest and in soybean at each distance to the forest in each site. An enclosure experiment was also conducted 5m from the forest edge in which 10 plants were selected, 6 floral buds per plant were marked, and 3 of these buds enclosed in voile bags. Flowers exposed to visitors displayed a higher number of seeds, higher fruit and seed weight, and a lower number of aborted fruits than bagged flowers.

33. Park, M., et al. "Wild Pollinators of Eastern Apple Orchards and How to Conserve Them." Cornell University, Penn State University, and The Xerces Society, 2012, <http://www.northeastipm.org/park2012>

Pollen must move across apple tree varieties, as they are self-incompatible, and all trees within a variety are clones. The most important wild pollinators of apple are ground nesting bees. Nests are built in well-drained soils to avoid moisture-loving microbes that attack food and young. Cavity-nesters: don't excavate their own nest, but find existing cavities to house their social colonies and honey supplies; are active all summer long; require constant (or long term) floral resources in the vicinity of the hive; ex. Honey bees, bumble bees. Tunnel-nesters: either excavate tunnels in wood (carpenter bees) or use abandoned cavities such as beetle burrows or cracks in masonry (mason bees – effective apple pollinators, populations can be increased through artificial nesting materials); require stems, trees, rotting logs, wooden structures, or old masonry for nesting. Small carpenter bees (*Ceratina* spp.) excavate nests in pithy stems, such as bramble. Piling old trees near the orchard is recommended for creating new nesting sites for both tunnel-nesters and social cavity-nesters. Includes species and bloom time for forage plants for wild pollinators: service berry, pussy willow, lupine, basswood, lance-leaf coreopsis, smooth penstemon, milkweed, purple coneflower, wild bergamot, joe pye weed, blue giant hyssop, giant sunflower, white meadowsweet, New England aster. Also includes information on toxicity of pesticides to bees.

34. Ricketts, Taylor H. "Tropical Forest Fragments Enhance Pollinator Activity in Nearby Coffee Crops." *Conservation Biology*, vol. 18, no. 5, Oct. 2004, pp. 1262–1271., doi:10.1111/j.1523-1739.2004.00227.x.

Forest remnants enhance pollinator activity in surrounding agricultural fields. Bee richness, overall visitation rate, and pollen deposition rate were all significantly higher in sites within approximately 100m of forest fragments than in sites farther away. Although *Apis mellifera* visitation rates were constant across the distance gradient, they accounted for a higher proportion of visits as distance from forest increased. Forest fragments, more so than a similarly bee-rich riparian strip, provided nearby coffee with a diversity of bees that increased both the amount and stability of pollination services by reducing dependence on a single introduced pollinator. Although *Coffea arabica* is autogamous, experiments have shown that yields decrease 15-50% when bee visitation is prevented. Bee activity was observed through visitation, defined as a bee landing on a flower and collecting resources from it, and pollen-deposition rates were measured by counting pollen grains on collected flower stigmas under a microscope.

35. United States, National Agroforestry Center. "Agroforestry: Sustaining Native Bee Habitat For Crop Pollination," 2008. *Agroforestry Notes*.

Black locust and maple trees supply abundant flowers and are excellent hardwoods that can at some time be harvested. Another simple way to provide pollinator habitat is to leave snags since many important native bee species nest in a snag's old beetle tunnels. Agroforestry plantings can also reduce wind and improve flying conditions for pollinators, which can also create slightly elevated temperatures around plantings, increasing the time that pollinators can be active. Bees are superior – and frequently the only – crop pollinators because they

transport pollen and typically visit flowers from a single plant species during each foraging trip, which ensures that the correct pollen is transferred from plant to plant. Trees that are good sources of pollen and nectar include black locust, maple, black cherry, horse chestnut, yellow (tulip) poplar, persimmon, and basswood – these trees also produce a harvestable wood product.

36. *USDA National Agroforestry Center. "Working Trees for Pollinators," USDA National Agroforestry Center, 2016.*

Illustrates some of the most important pollinators for food production and their habitat needs, and how agroforestry practices can be adjusted to support pollinators, and also provide multiple benefits for producers. Some crop flowers require sonication or "buzz pollination," including tomatoes, blueberries, and cranberries—honey bees do not buzz pollinate. Specialist ground-nesting bees pollinate squash, sunflower, okra, and other crops. Some wood nesting bees are managed for the pollination of alfalfa and tree fruits. Native bunch grasses, brush piles, or even piles of field stones provide habitat for bumble bee nests. Bumble bees are among the most important pollinators of certain berry crops. Describes agroforestry practices designed for pollinators: windbreaks or hedgerows; forest farming; riparian forest buffers; alley cropping (growing plants in close proximity that have complementary flowering periods; and silvopasture, practicing rotational grazing, thinning, and prescribed fire. Many valuable overstory crop trees, like yellow (tulip) poplar, maple, basswood, and black cherry provide excellent pollinator habitat. Cultivated understory plants, such as ginseng, goldenseal, and black cohosh may benefit from pollinator visits. Flies are likely important since some flies are active in cooler temperatures, when many of the forest crops flower. Also mentions black cherry, black locust, and basswood as flowering trees.

Forest Pollinators and Habitat Fragments

37. *Cunningham, Saul A. "Depressed pollination in habitat fragments causes low fruit set." Royal Society, vol. 267, 2000, pp. 1149-1152.*

In central New south Wales, Australia, flowers of *Acacia brachybotrya* and *Eremophila glabra* plants growing in linear vegetation remnants received less pollen than conspecifics in nearby reserves. Pollen supplementation increased fruit production by both species, indicating pollen limitation of fruit set. This study confirms that habitat fragmentation can lead to decline in pollination and subsequent fruit set in wild plant populations. Pollination of flowers was determined by counting the number of pollen grains on flowers' stigmatic surface under a light microscope. Some issues with non-randomness in the study. It is unclear if declines in fruit production of the 2 plants are sufficient to endanger the fragmented populations.

38. *Farwig, Nina, et al. "Isolation from Forest Reduces Pollination, Seed Predation and Insect Scavenging in Swiss Farmland." Landscape Ecology, vol. 24, no. 7, 16 June 2009, pp. 919–927., doi:10.1007/s10980-009-9376-2.*

The proportion of flowers setting seed was significantly reduced by isolation from forest. Seed predation and insect scavenging were significantly lower at isolated sites than at sites connected to woody habitat. Pollination success, seed predation, and insect scavenging were negatively affected by isolation from forest. Variation in woody or open semi-natural habitat cover did not appear to affect the functioning of the studied ecosystem processes. Decreasing ecosystem services at isolated sites can be related to mobility constraints of pollinators, predators, and scavengers.

39. Proesmans, Willem, et al. "Importance of Forest Fragments as Pollinator Habitat Varies with Season and Guild." *Basic and Applied Ecology*, vol. 34, Feb. 2019, pp. 95–107., doi:10.1016/j.baae.2018.08.004.

Small forest fragments can play an important role in conserving pollinators, especially bees and saproxylic hoverflies, and are most important in spring, when the herb layer provides foraging resources. The pollinator community in the edges of small forest fragments is strongly influenced by forest and forest edge characteristics. Old forest fragments with a well-developed herb layer had more diverse bee communities than recent forests or old forests without a herb layer, but overall lower activity-abundances, while sun exposure of the forest edges had a strong positive effect on pollinator activity-abundance in general. The hoverfly community had higher activity-abundances in forest edges with a higher flower-index, while saproxylic hoverflies were caught in higher numbers in sites with a higher forest cover in the surrounding landscape. The effects of herb layer cover on bee species richness and activity-abundance were much stronger in spring than in summer, while bee species richness was also strongly positively correlated with forest age in spring. A positive correlation between pollinator species richness and sun exposure was found, and was even stronger in summer, after canopy closure. The authors attributed the scarcity of cavity-nesting bees to the low amount of dead wood in the studied forest fragments. Species that fly in spring may benefit from the presence of forest fragments, while species that are active in summer may show a negative association with forests due to low light exposure and lack of floral resources.

Forest Pollinators and Adjacent Land Use

40. Connelly, Heather, et al. "Landscape Simplification Decreases Wild Bee Pollination Services to Strawberry." *Agriculture, Ecosystems & Environment*, vol. 211, 2015, pp. 51–56., doi:10.1016/j.agee.2015.05.004.

The authors evaluated the influence of landscape simplification on the composition of pollinator communities and the provisioning of pollination services to cultivated strawberry. Pollinators were collected during bloom with pan traps from commercial farms, chosen to represent a gradient in the proportion of agricultural land uses in the surrounding landscape from .09 to .6. Landscapes with greater proportions of agricultural area had lower pollinator abundances and species richness. Agricultural product yield was positively correlated with pollinator abundance, but species richness had little effect on the level of pollination services. They also found that visitor identity did not explain pollination efficiency in strawberry. The results showed that even in a region characterized by many small semi-natural areas, a high proportion of agricultural land in the landscape negatively effects wild pollinators and pollination services to strawberry at both the 750m and 1km scales. Strawberries are self-fertile, but visitation from pollinating insects can increase fruit weight by as much as 40% over wind pollination alone. The authors also observed single visits to virgin secondary flowers and compared the weight of the resulting fruit to that of the other unvisited secondary flower on the same inflorescence in order to determine individual pollinator efficiency. Although previous work in the region did not report landscape effects on the pollinator community visiting watermelon and pumpkin (Winfree et al., 2008), the community of bees pollinating strawberry is comprised of species smaller in average body size, which are thought to be more sensitive to landscape metrics. Only marginal differences in pollination efficiency of strawberry were found among honey bees and the four most common wild bee genera. On average, a single visit by a bee to a virgin strawberry flower was sufficient to increase yield by 38%.

41. Flicker, Nathaniel Ryan, et al. "The Bee Community of *Cannabis Sativa* and Corresponding Effects of Landscape Composition." *Environmental Entomology*, vol. 49, no. 1, 2 Dec. 2019, pp. 197–202., doi:10.1093/ee/nvz141.

The authors characterize the bee community visiting hemp along a landscape gradient to determine how shift in landscape composition affects hemp's bee community. Industrial hemp (*Cannabis sativa*) is an exclusively wind-pollinated crop – it lacks nectar but produces an abundance of pollen during a period of floral dearth (late summer) in agricultural landscapes. The authors made repeated sweep net collections of bees visiting male hemp flowers (they don't visit female flowers, and therefore don't pollinate hemp) in 20-minute sampling transects/plot perimeters on farms in NY and found that hemp supported 16 different bee species. Sampling was conducted between July 30 and September 15. Landscape simplification negatively impacted the abundance of bees visiting hemp flowers but did not affect the species richness of the community. Plant height was strongly correlated with bee species richness and abundance for hemp plots with taller varieties attracting a broader diversity of bee species. Hemp's pollinator community may vary temporally as bees respond to local declines in the availability of floral resources when the flowers of other late-season crops in the landscape senesce. Data were analyzed separately for *Apis mellifera* and wild bees. The authors found a negative impact of agricultural cover on the abundance of wild bees visiting hemp. Nearly 60% of hemp's bee community was *A. mellifera*, and nearly 30% were *B. impatiens*, a generalist pollinator intensively relied upon in wild and managed contexts for agricultural pollination services. The abundance of bees visiting hemp plants also increased throughout the sampling period, which may reflect the increasing importance of hemp as a pollen-forage resources as the flowers of other late-season crops senesce at the end of the summer. At the landscape level, hemp plantings located at sites with moderate agricultural cover are also likely to support a more abundant population of crop pollinators, as the authors found that the number of wild bees visiting hemp declined as the proportion of agricultural cover in the landscape increased. The average number of species utilizing hemp did not vary with landscape context, suggesting that hemp will support a broad array of crop pollinators across a range of landscape contexts. Observed shifts in community composition were driven mainly by differences in forest and seminatural habitat cover, suggesting that hemp will support a different suite of species in landscapes with more open natural habitats, such as meadows and shrublands, compared with landscapes with greater forested cover, reflecting variation in habitat requirements and life cycle characteristics of different bee species. An important consideration mentioned by the authors is that incorporating novel pollens into the diets of generalist bees has been shown to have detrimental effects on larval development, so future research should address the relative value of hemp pollen in supporting bee reproduction.

42. Grab, Heather, et al. "Agriculturally Dominated Landscapes Reduce Bee Phylogenetic Diversity and Pollination Services." *Science*, vol. 363, no. 6424, 18 Jan. 2019, pp. 282–284., doi:10.1126/science.aat6016.

This study links landscape-mediated changes in the phylogenetic structure of natural communities to the disruption of ecosystem services. The authors combined a time-calibrated genomic phylogeny with extensive pollinator community and pollination datasets from apple orchards over 10 years. They found that species loss due to agriculturally driven land-use change is not random across the bee phylogeny – some branches contain more closely related species in highly agricultural landscapes compared with those found in landscapes with less agricultural cover. This cannot be attributed to species richness declines alone. The authors estimate that pollinator communities lose 35 million years of evolutionary history for every 10% increase in agricultural cover within the landscape. The data suggest that land-use changes are pruning lineages from the more complete communities present in landscapes with low agricultural cover, as opposed to complete species turnover. Closely related species responded to increasing agricultural land cover more similarly than species pairs selected at random. The clades most resilient to land-use change included *Bombus* and *Lasioglossum*, and the clades

sensitive to land-use change include *Andrena*, perhaps because *Andrena* are solitary and have a narrow flight phenology.

43. Grab, Heather, et al. "Habitat Enhancements Rescue Bee Body Size from the Negative Effects of Landscape Simplification." *Journal of Applied Ecology*, vol. 56, 2019, pp. 2144–2154., doi:10.1111/1365-2664.13456.

Landscape simplification has been associated with size declines across bee taxa and smaller body size can be an early indicator of environmental stress. Body size of 10 wild bee species was measured at 70 sites with or without floral habitat enhancements in Michigan and New York. Bees were collected at sites with varying amounts of agriculture in the surrounding landscape, allowing us to test whether morphological responses to enhancements are affected by landscape simplification. Half (5) of the bee species measured exhibited declining body size across the landscape gradient. Among these species, declines were buffered by the presence of habitat enhancements suggesting this response is the result of improved nutrition, reduced need for long-distance foraging, enhanced recruitment of larger individuals or a combination of these mechanisms. Declines in body size were strongest in both the smallest and largest species. Large and medium sized species exhibited the greatest response to flowering habitat enhancements. The authors did not observe decreased body size in any species at sites with a flowering habitat enhancement, suggesting these resources can support wild bees experiencing stress from intensively managed agricultural landscapes across multiple cropping systems and regions. Habitat enhancements are most effective in simple, agriculturally dominated landscapes where they result in a high contrast between the local availability of floral resources and those available in the broader landscape. Roulston and Cane (2000) suggest that body size plasticity among wild bees is greatest in stem-nesting species due to the inherent variation in the size of the nest cavities that they use. In this case, the observed increase in body size at enhanced sites along the landscape gradient could be due to greater utilization of larger diameter plant stems in the habitat enhancements compared to the surrounding environment. The authors did acknowledge that their sampling method and data had a potential for bias towards species that are already tolerant of human disturbance.

44. Grover, Shannon N., et al. "Indirect Effects of Landscape Spatial Structure and Plant Species Richness on Pollinator Diversity in Ozark Glades." *Castanea*, vol. 82, no. 1, Mar. 2017, pp. 24–31., doi:10.2179/16-108.

Examines the direct and indirect effects of landscape structure on plant and pollinator communities in the naturally patchy, dolomite glade grasslands of the Missouri Ozarks. Higher pollinator diversity was not directly related to greater landscape area and connectivity. However, the authors did find evidence for an indirect relationship where better-connected landscapes support higher plant richness, which in turn supports greater pollinator diversity. Glades typically occur on ridgetops and south- and west-facing slopes, where intense insolation, in conjunction with harsh soil conditions and frequent, low-intensity fires, create an environment that generally does not support woody plant dominance. Their harsh, xeric nature makes them poorly suited to anthropogenic uses, so they represent a relatively intact system in comparison to most Midwestern grasslands. Glades also contain a high number of endemic and rare plant species relative to other Midwestern grasslands. Pollinators were surveyed through visual observation between 9am and 5:30 pm on days with little to no cloud cover and temperatures exceeding 24 deg C. Every bee, butterfly, wasp, or hoverfly observed within the 50mx2m study plot over the course of 10 minutes (walking 5m/min down the center) was morphotyped visually based on characteristics distinguishable in the field. Because morphological diversity approximates pollinator functional diversity, richness of the observed morphoguilds was used as a proxy for pollinator diversity, albeit with the potential for underestimation of pollinator richness. Plants appeared to be more sensitive than pollinators to landscape spatial structure. One explanation could be that the woodland matrix surrounding glades presents a more hostile environment to plant dispersal than to pollinator dispersal – pollinators use

forested land for other life history functions, while plants can't grow or disperse seeds through wooded landscapes. Increased plant richness associated with well-connected landscapes appeared to have a positive influence on pollinator diversity, suggesting that resources available in glades might be more limiting to pollinator diversity than resources (e.g. nesting sites, materials) found in the woodland matrix.

45. Taki, Hisatomo, et al. "Landscape Effects of Forest Loss in a Pollination System." *Landscape Ecology*, vol. 22, no. 10, 2007, pp. 1575–1587., doi:10.1007/s10980-007-9153-z.

A study using *Erythronium americanum*, a bee-pollinated herb. Bees were sampled using pan traps. Found that the abundance and species richness of all collected bees were positively related to only the forest cover at a 750 m radius. The species richness of pollen-foraging bees was not affected by forest loss. None of the bee assemblages and species was affected by the effects of forest edge amount. Diverse insect species, including male and non-pollen-foraging (cleptoparasitic) bees seem to be effective pollinators for *E. americanum*. Forest loss had significantly negative impacts on bee communities and seed sets in populations of self-incompatible *E. americanum*.

46. Williams, Neal M., and Rachael Winfree. "Local Habitat Characteristics but Not Landscape Urbanization Drive Pollinator Visitation and Native Plant Pollination in Forest Remnants." *Biological Conservation*, vol. 160, Apr. 2013, pp. 10–18., doi:10.1016/j.biocon.2012.12.035.

Greater pollinator abundance and associated diversity significantly reduced the degree of pollen limitation, demonstrating that pollinator populations are critical to successful pollination of these plant populations (*Claytonia virginica* and *Polemonium reptans*). Patch-level characteristics, and not landscape context, significantly affected pollinator visitation, with pollinators being more abundant in brighter woodland patches for *Claytonia*, and in larger patches for *Polemonium*. Local-scale woodland area affected the composition of flower visitors at *Claytonia* arrays but not at *Polemonium* arrays. Light level was important for determining abundance of flower visitors, but not the composition of the visitors for either plant species. Urbanization may represent habitat change rather than loss – in this experiment the surrounding land was suburban or exurban and could still support many pollinators. The authors used a phytometer experiment in which they placed standardized arrays of spring wildflowers within woodland habitats that differed in the extent of forest cover versus urban land cover in the surrounding landscape, and also in local habitat variables such as woodland fragment size. "Visitation" to a flower was defined as an insect making contact with sexual parts of a female-phase flower for >0.5 seconds, and flowers were observed during 12 5-minute sample periods through one day.

47. Winfree, Rachael, et al. "Effect of Human Disturbance on Bee Communities in a Forested Ecosystem." *Conservation Biology*, vol. 21, no. 1, 2007, pp. 213–223., doi:10.1111/j.1523-1739.2006.00574.x.

The authors studied bees in a forested, ericaceous heath and how they are impacted by human land use at the landscape and local scales in southern New Jersey. Bee abundance and species richness within forest habitat decreased with increasing forest cover in the surrounding landscape. Bee abundance and species richness were greater in agricultural fields and suburban and urban developments than in extensive forests. 18 of the 130 bee species studied were positively associated with extensive forest and are listed in the paper, but these bees were not more likely to be oligolectic or to require wood for nesting. The authors concluded that for this system, moderate anthropogenic land use may be compatible with the conservation of many, but not all, bee species. Data was collected at each site with one 110x10 m transect, sampling bee diversity and flower abundance four

times per site during the peak season of bee activity. Bees were sampled using hand netting and pan trapping. Agricultural fields had the highest bee abundance, species richness, and richness of unique species, although the results were not significant for species. For obligate wood-nesting bees, the authors found a significant negative association with forest habitat at the landscape scale but a significant positive association at the local scale. This suggests that wood for nest sites is not limiting over the range of variation examined in the landscape-scale study, but that it may become limiting once forests are removed completely. Different bee species may occupy different successional stages in a disturbed landscape, making total species richness higher than in less-disturbed landscapes, or bee species richness may be maximized at an intermediate level of human disturbance. The type of ecosystem studied, and the floral resources available there, may determine how bees are affected by human land use. In forested regions, many bees have been originally associated with natural disturbances and may now be able to use areas disturbed by humans.

Forest Pollinators and Invasive Plants

48. Hanula, James L. and Scott Horn. "Removing an exotic shrub from riparian forests increases butterfly abundance and diversity." *Forest Ecology and Management*, vol. 262, no. 4, 2011, pp. 674-680, doi:10.1016/j.foreco.2011.04.040

The authors investigated the effects of the invasive shrub Chinese privet and of removing it from riparian forests on butterfly communities. Privet was either mulched or hand-felled in experimental plots, hand-felled privet was left in place once cut. Control plots were heavily invaded with privet. Other study plots were in "desired future condition" forests which had never had extensive privet cover. Two years after removing Chinese privet, the plots had much more diverse, abundant, and distinctly different plant communities than untreated control plots. However, these plant communities were also distinctly different from the communities in desired future condition forests – privet removal plots had plant communities composed mostly of early colonizers of disturbed areas. Plots where privet was mulched had greater herbaceous cover compared to the felled plots and had higher butterfly abundance. Butterfly species richness and diversity were also correlated with herbaceous plant cover however it was not clear if this was a direct relationship. The mulching machine also caused soil disturbance, which has been previously suggested as a management tool to improve grasslands for butterflies. Notably, bee communities on desired future condition plots were very similar to the privet removal plots regardless of removal method.

49. Hanula, James L. and Scott Horn. "Removing an invasive shrub (Chinese privet) increases native bee diversity and abundance in riparian forests of the southeastern United States. *Insect Conservation and Diversity*, vol. 4, no. 4, 2011, doi:10.1111/j.1752-4598.2011.00131.x

The same experimental setup as the previous article, but sampling for bees using pan traps. Privet shrub removal, regardless of method, resulted in three times as many bee species on removal plots compared with untreated control plots the first summer following removal. There was no significant difference in the bee communities between mulched and hand-felled plots. Removing Chinese privet resulted in large increases in bee abundance and diversity. By 2007, desired future condition plots had a similar bee community to both the felling and mulched treatments.

50. McKinney, Amy M. and Karen Goodell. "Shading by invasive shrub reduces seed production and pollinator services in a native herb." *Biological Invasions*, vol. 12, 2010, pp. 2751-2763, doi:10.1007/s10530-009-9680-4

The authors quantify and identify mechanisms of direct and indirect effects of an invasive shrub on pollination and reproductive success of a native herb. Sites with the invasive shrub had significantly lower light, pollinator visitation rate, and conspecific pollen deposition to the native herb than in plots where the shrub was removed. The authors ruled out competition for pollinators as a factor of limited herb success, since removing the shrub flowers but leaving the shrub did not increase pollinator visitation or pollen deposition for the herb. They conclude that the mechanism of impact of the shrub on herb reproduction was increased understory shade caused by shrub growth. Because less light did not correspond to a change in temperature in this study, the authors suggest the effect may be due to shading making the herb flowers less vibrant and visible in low light areas, or the shrub layer obscuring the flowers and making them more difficult for pollinators to find.

51. McKinney, Amy M. and Karen Goodell. "Plant-pollinator interactions between an invasive and native plant vary between sites with different flowering phenology." *Plant Ecology*, vol. 212, 2011, pp. 1025-1035, doi:10.1007/s11258-010-9882-y

In the previously listed study (above), the authors found that shading from an invasive shrub decreased pollinator visitation of a native herb. In this study, the same authors looked at flowering phenology and its impact on this relationship. When the invasive shrub flowered asynchronously with the herb, the herb experienced lower pollinator visitation. However, when the shrub flowered synchronously with the herb, the herb received more pollinator visits and produced more seeds per flower (a 63% increase in seed set) compared to plots where the invasive shrub was absent, suggesting that the co-flowering invasive shrub actually facilitated pollination of the herb, mitigating the negative impacts of shading and increasing herb seed production. Synchronous flowering also attracted more pollinator taxa than in plots where the shrub was absent. The authors note that their study lacks the replication necessary for a rigorous test of the effects of phenological variation on the impacts of the invasive shrub on native plant pollination.

Pollinator Research Methodology

52. Campbell, Joshua W., and J. L. Hanula. "Efficiency of Malaise Traps and Colored Pan Traps for Collecting Flower Visiting Insects from Three Forested Ecosystems." *Journal of Insect Conservation*, vol. 11, no. 4, 8 Feb. 2007, pp. 399-408., doi:10.1007/s10841-006-9055-4.

Malaise trap design and color of pan traps are important parameters that influence insect pollinator catches. The authors compared pan trap (blue, yellow, white, red) and Malaise trap catches from forests in the Piedmont, Coastal Plain, and Blue Ridge regions of the southeastern US. Similarities in trap performance between sites were observed with blue pan traps being most effective overall. Various pollinator groups preferred certain pan trap colors and adding color to Malaise traps influenced insect pollinator catches. Pan traps generally caught more pollinators than Malaise traps. Because of their low cost and simplicity, using several colors of pan traps is an effective way to sample relative abundance and species richness of flower-visiting insects. Various yellow traps have been used to catch a wide variety of phytophagous insects (Kirk 1984) and predators (Leksonoet al. 2005), blue pan traps catch various Hymenoptera (Aguiar and Sharkov 1997), and white or yellow traps catch many Diptera (Disney et al.1982). Bees and various other flower-visiting insects respond to common floral colors (Kirk 1984) associated with floral rewards (pollen/nectar) (Leong and Thorp 1999). Malaise traps capture large numbers and high diversities of flying insects including Hymenoptera and have been used widely in surveys of insect abundance and diversity. The authors also used canopy Malaise traps

which allow insects to be caught from any direction and have collecting containers at both the top and bottom of the traps. Pollination effectiveness was not measured so insects captured were thought of as floral visitors rather than pollinators. Detailed descriptions are included for each landscape type as to which traps worked best for which orders and families of floral visitors. Many Hymenoptera are able to discern shorter wavelengths of visible light better than longer wavelengths, which may explain why they overall preferred the blue pan traps at all three sites. Hymenoptera may be unable to distinguish well between white and blue pan traps and are considered “red blind.” Some bees that flew into Malaise traps were able to escape. Butterflies have more complex vision patterns in relation to color. It appears that syrphid flies are highly attracted to blue colors. Captures of flower-visiting insects were most similar in blue and white pan traps on all three sites. The authors concluded that a combination of blue, white, and yellow pan traps were effective for assessing the abundance and species richness of diverse communities of flower visitors in the three forests, and that other parameters (trap height, duration of trap placement, etc.) may influence trap captures.

53. Giles, Valerie, and John S. Ascher. “A Survey of the Bees of the Black Rock Forest Preserve, New York.” *Journal of Hymenoptera Research*, vol. 15, no. 2, 2006, pp. 208–231., https://www.researchgate.net/publication/284697226_A_survey_of_the_bees_of_the_Black_Rock_Forest_Preserve_New_York_Hymenoptera_Apoidea

Surveys were conducted with nets, bowls, and trap nests – the net-collected sample was richer than the bowl-trapped sample in total bee species and in the number of unique species, but the net-trapped sample was biased against some of the most common and readily identified taxa. Important habitats for bees at Black Rock Forest (BRF) include small meadows, exposed road edges and reservoir edges, dams, and marshes, where flowering shrubs and herbs provide seasonal sources of pollen and nectar to bees (*Viburnum* spp., *Ilex verticillata*, *Kalmia latifolia* L., *Clethra alnifolia* L., *Spiraea* spp., *Rhododendron* spp., *Veronica*, *Polygonum* spp., *Gnaphalium*, *Solidago* spp., *Viola* spp.). In addition, during early spring (April) prior to leaf-out, forest habitats hosted bees attracted to flowering trees such as *Acer rubrum* L., *Salix* spp. including *S. discolor* Muhl. And *Prunus* spp. In May, other flowering trees such as *Craetagus macrosperma* Ashe. and other *Prunus* spp. were important resources for many *Andrena* and other bee species. They conducted bee surveys between March and October, from around ~0730 hr to 1800 or 1900 hr. Individual traps were placed ~1m apart. Only a single bee was captured in a trap nest, which were occupied predominantly by wasps. *Colletes* is only captured in bowl traps infrequently. *Colletes inaequalis* is often encountered collecting pollen from maples but was surprisingly absent from net-collected samples in early spring. The abundance of *Augochlora pura* in their samples probably reflects the local availability of rotting logs in which this species excavates its nests. *Lasioglossum* individuals were expectedly abundant in the bowl samples. For the Andrenidae, species associated with blueberry were particularly well represented including the *Vaccinium* oligoleges *A. bradleyi* and *A. rufosignata*. *A. cornelli* is now thought to be a *Rhododendron* specialist. *Andrena violae* is an oligolege of *Viola*, which is also often visited by long-tongued bees like *Osmia*. Other oligolectic *Andrena* at BRF include *A. krigiana*, a specialist of *Krigia* (dwarf dandelion), and *A. fragilis*, a specialist of *Cornus* (*Svida*). Three *Andrena* specialists of *Solidago* and *Aster* were found – *A. hirticincta*, *A. nubecula*, and *A. simplex* – as was the panurgine Astereae specialist *Pseudopanurgus andreoides*. *Andrena arabis* is a specialist that may actually benefit from the spread of invasive garlic mustard. Many species that regularly collect pollen from rosaceous trees and shrubs and are known or suspected to be important pollinators of apples were collected in good numbers, including *A. miserabilis*, *A. (Melandrena)* spp., and *A. (Trachandrena)* species. The authors’ sample of eight native *Osmia* species includes series of the forest-associated *O. bucephala* and *O. pumila*. The sample of native *Megachile* and associated *Coelioxys* cleptoparasites may reflect the inefficiency of bowl traps for capturing these strong-flying species. *B. perplexus* and *B. vagans* are both generally numerous in New York forests and bogs. Introduced bee species found included: *Megachile sculpturalis*, giant

resin bee; *Osmia cornifrons*, horn-faced mason bee; *Anthidium oblongatum*. Includes an Appendix with seasonal patterns of occurrence. The authors posited that where flowers are scarce, bowl traps may be particularly effective due to lack of competition from real flowers.

54. Grootaert, Patrick, et al. "Sampling Insects: General Techniques, Strategies and Remarks." *Manual on Field Recording Techniques and Protocols for All Taxa Biodiversity Inventories and Monitoring*, edited by Jutta Eymann et al., vol. 8, 2010, pp. 377–399. ABC Taxa.

Isolated here are mostly methods discussed in other literature, as they have been shown to be effective for pollinators, but this source includes information on both active collecting – pooter, portable suction devices, sweepnet, visual observation – and passive collecting – colored pan traps, emergence traps, sticky traps, suction traps. Trapping devices can be separated into attraction traps and interception traps, although some combine both methodologies. Includes a table of recommended sampling methods by taxa. The species diversity in sweep net samples often resembles that of Malaise trap yields. When sweep netting, make sure to use the right nest size, sweep gently, watch out for stinging insects, and transfer the sample to a collecting jar after a limited number of sweeps to avoid damaging specimens. Sweep netting cannot be done when vegetation is humid or highly thorny. Visual observation is another important tool, especially for learning about insect behavior, although it is strongly recommended to collect voucher specimens to confirm their identity in the lab. For pan traps it is important that they are weather-proof and that the color won't change over time. Bright yellow traps are the most widely used and attract a broad spectrum of low-flying insects, in particular Hymenoptera and predacious flies. White pan traps have been shown to be excellent at collecting Syrphidae and Dolichopodidae. Arboreal dolichopodid species are collected best in blue traps and soil-dwelling species in red (and blue) traps. Other dipteran families with larvae that breed in plant tissue, such as *Chloropidae*, are most attracted by blue pan traps. Depending on the servicing periodicity of pan traps, salt can be added as a preservative (longer than daily or every two days), or formalin to extend the sampling interval. Light traps are operated at night and are most effective from sunset until after midnight with clouded skies. Especially drizzly weather conditions are very productive, both in terms of species and specimens. This technique is generally applied for the collection of moths, scarabaeid beetles (Coleoptera, Scarabaeidae), and some Hemiptera and Hymenoptera.

55. McCravy, Kenneth W., and Jared D. Ruhoff. "Bee (Hymenoptera: Apoidea) Diversity and Sampling Methodology in a Midwestern USA Deciduous Forest." *Insects*, vol. 8, 4 Aug. 2017, doi:10.3390/insects8030081.

Bee diversity and sampling methodology were studied in an Illinois, USA upland oak-hickory forest using elevated and ground-level pan traps, malaise traps, and vane traps. Elevated pan traps collected the greatest number of bees, but ground-level pan traps collected greater species diversity than elevated ones. Elevated and ground-level pan traps collected the greatest bee species richness. Among pan trap colors/elevations, elevated yellow pan traps collected the greatest number of bees but the lowest diversity. Malaise traps were relatively ineffective. Vane traps collected relatively low species richness. Bee species composition differed significantly between elevated pan traps, ground-level pan traps, and vane traps. Indicator species were significantly associated with each of these trap types, as well as with particular pan trap colors/elevations. Pan traps are colored pans or bowls that are usually placed on the ground, or sometimes elevated, and filled with a liquid such as soapy water that traps and kills the insects. Malaise traps are mesh-fabric flight interception traps, with the Townes-style trap being a commonly used type; they have proven effective in collecting bees and other Hymenoptera. Vane traps consist of two cross vanes with a collection container underneath. Insects contact the vanes and fall into the collection container. Vane traps have also been shown to be effective in collecting bees, particularly bumble bees. Pan traps and collection containers of vane and malaise traps were filled with water containing a few drops of dishwashing detergent to break surface tension, and were operated on clear, warm,

calm days. ACE and Chao1 analyses suggested that substantially more species of bees remained to be collected – only vane-trap-observed species richness approached asymptotic richness, however, blue vane traps were the most effective method of collecting bumble bees. Pan color effectiveness can vary locally in relation to habitat. Incorporation of search-and-net collecting using insect nets to target specific bee species could increase species yield while limiting destructive sampling. This method can be especially effective when efforts are focused on particular host plants to collect oligolectic bees. The effectiveness of malaise traps in collecting bees may also be habitat-specific.

56. Nuttman, Clive V., et al. "The Utility of Aerial Pan-Trapping for Assessing Insect Pollinators Across Vertical Strata." *Journal of the Kansas Entomological Society*, vol. 84, no. 4, 2011, pp. 260–270., doi:10.2317/jkes110319.1.

The authors surveyed and compared the species richness and abundance of a wide range of insect pollinators in agricultural, secondary regenerating forest and primary forest habitats in Ghana to evaluate the usefulness of aerial pan trapping. They confirmed the efficacy of the method at heights of up to 30m and the effects of trap color on catch. They also found the greatest insect abundance in agricultural land and higher bee abundance and species richness in undisturbed forest compared to secondary forest. The authors say of pan trap color: in general, yellow is most effective for Hymenoptera and Diptera; white also attracts Diptera and some grass-dwelling insects but may repel some Hymenoptera; red is good for some Coleoptera; and neutral colors like brown or grey have low overall attractiveness but the added advantage of low selectivity. The pan traps used in the study were spray painted blue, yellow, and white and left out for 48 hours. All groups of pollinators, except butterflies and moths, exhibited clear differences in abundance across the three habitat types. The number of bees, stingless bees, wasps, and beetles was highest in the agricultural matrix. Blue pans were most attractive to bees (excluding stingless bees) while the remaining taxa all showed a preference for yellow pans. Blue pans also contained the greatest species richness of bees. Yellow pan traps were favored by butterflies and beetles. While the abundance of bees in yellow and white pans was lower, they still contained some species not collected in the blue pans. Supplementary to other active survey methods, aerial pan traps sample a component of the flower visitors that would otherwise be missed across vertical strata and they can be placed and left running for long periods, requiring little technical expertise.

57. Portman, Zachary M., et al., "The State of Bee Monitoring in the United States: A Call to Refocus Away From Bowl Traps and Towards More Effective Methods." *Annals of the Entomological Society of America*, vol. 113, no. 5, 2020, pp. 337-342, doi:10.1093/aesa/saaa010

Outlines the drawbacks of bowl traps and other passive sampling methods, emphasizing that current methods do not monitor changes in bee abundance. Bowl traps collect a filtered version of the bee fauna – some species/genera (Halictidae) are caught very often while others not at all. It is also unclear what proportion of a bee population is caught by a bowl trap, and whether the proportion varies by species or sex. The presence of flowers in the survey area may also influence bowl trapping results, but how is still unknown. It is also not clear how other factors, such as proximity to nest sites or the age or experience of bees may influence bowl trap catch rates. Finally, bowl traps were not used by historic collectors, making data collected using them difficult to compare to historical data. The authors propose improving our understanding of the efficacy and drawbacks of current methods, novel molecular methods, nest censusing, mark-recapture, sampling of focal plant taxa, and detection of range contractions. They also suggest netting as a more targeted approach, as researchers can reduce the number of specimens collected, as well as gain data on floral relationships while addressing specific monitoring goals. Studies are needed that combine mark-recapture with trapping to compare trap effectiveness to actual abundance.

58. White, Erin L., et al. *Empire State Native Pollinator Survey Participant Handbook, New York Natural Heritage Program, 2018.*

The goal of the Empire State Native Pollinator Survey is to determine the conservation status of a wide array of native insect pollinators in nonagricultural habitats. Target species/focal taxa were chosen to highlight the important role a variety of native insects play in pollination, so at least one species group from each of the primary insect orders known to pollinate native plants was chosen. Within these orders, groups of species were selected that 1) have been documented or are suspected to be important pollinators; 2) have poorly understood conservation status; 3) contain known or suspected at-risk species in the Northeast or elsewhere, including those that are naturally rare and those whose populations have declined or distributions have decreased; 4) are not so diverse that determining the conservation status of most of the species may be an unreachable goal; 5) may feasibly be identified to species by trained biologists, experts who may be project partners, and/or citizen scientists; and 6) may be appealing for a citizen-science effort. The conservation status of most butterflies has previously been assessed, so that group was not selected for the statewide surveys. Known rare species that are not expected to be detected with sufficient frequency using the extensive approaches, particularly those needing resurveys of specific locations, will be the focus of target species surveys completed by NYNHP staff. In general, they recommend doing observations and surveys from about mid-April through mid-October. Most of the targets will be most active during the warmest parts of the day, from mid-morning until late afternoon. In general, optimal conditions are warm, dry, sunny days of at least 70 deg F. Includes detailed instructions on hand-netting technique, processing procedure for soapy water specimens, bowl trapping, storing, and shipping.

Misc.

59. Burkle, Laura A., and Tiffany M. Knight. "Shifts in Pollinator Composition and Behavior Cause Slow Interaction Accumulation with Area in Plant–Pollinator Networks." *Ecology*, vol. 93, no. 11, 2012, pp. 2329–2335., doi:10.1890/12-0367.1.

The authors investigated plant-pollinator interaction networks of the herbaceous rocky outcrop communities in Ozark glades (Missouri) of different areas. They quantified the degree to which the increase in the number of species interactions with area differed from a null model based on sampling, where numbers of individuals increase with area. The observed rate of plant-pollinator interactions increase was considerably lower than expected. The authors found support to suggest that this is due to a higher proportion of specialist species in larger glades. Generalist pollinators were more selective in smaller glades. The authors suggest that if these results are can be applied generally, larger habitats may be needed to conserve interactions than would be thought based on species accumulation curves. Two non-mutually-exclusive mechanisms can contribute to any deviations in the rise of interaction richness with increasing area beyond sampling, including the overall degree of diet generalization and specialization, which is a property of the species, and the degree of flexibility in diet selectivity, which can differ across individuals within a species. Smaller glades were not as species rich for plants as larger glades. Sampling took place during peak pollinator activity (0800-1430 hours) on sunny, windless days, and each insect was swabbed for pollen with a cube of fuschin dye to evaluate pollinator fidelity. Because the plant and pollinator species were nested subsets across glades (i.e. species-poor glades contain frequently occurring species, whereas glades that are more species rich contain both frequent and less common species), the authors sought to determine whether glade area was a main contributing factor to the nestedness and presence of species. They also tallied the overall diet breadth of each pollinator species across all glades and calculated the mean diet breadth of pollinator species present in each glade. The number of interactions per species increased with glade area, but the species present in smaller glades behaved differently in larger glades and failed to fulfill their interaction potential in small glades. If individuals in small glades are more limited by factors other than floral resources (e.g., nesting sites) in small glades, they might forage only on their most

preferred foods there. The decreased selectivity of pollinators in large glades represents the summed population-level resource use of the species.

60. Meier, Albert J., et al. "Possible Ecological Mechanisms for Loss of Vernal-Herb Diversity in Logged Eastern Deciduous Forests." *Ecological Applications*, vol. 5, no. 4, 1995, pp. 935–946., doi:10.2307/2269344.

The authors suggest five possible ecological mechanisms for loss of diversity and lack of recovery of vernal herbs (any herbaceous species visible on the forest floor before canopy closure in late spring) in logged stands:

(1) loss of diversity as a result of logging disturbance – logging disturbs or removes less-common species, less common species may have more specific environmental requirements and be less able to tolerate microclimatic changes initiated by logging; diversity of vernal herbs is higher in primary forest than in recently clear-cut stands

(2) physiological stress and competition with weedy or exotic plant species soon after logging and during succession – more disturbance-tolerant genera may displace populations of more diverse, less disturbance-tolerant forest-floor herbs; clear-cutting can change soil moisture and temperature; open successional sites and the initial stages of forest regrowth may also be more prone to browsing by white-tailed deer

(3) low rates of reproduction and slow growth of forest-floor herbs – slow vegetative growth may reflect a K-strategy of restrained investment in reproduction and growth and increased allocation of resources to energy and nutrient storage in an environment where competition is severe for soil nutrients or light at the herbal canopy layer

(4) limited spread and slow dispersal due to clonal reproduction and gravity- or ant-mediated dispersal of seeds – many understory herbaceous plants are functionally clonal and long-lived; landscape features including high elevations, dry ridges, and agricultural fields would be expected to present impassable barriers to dispersal

(5) loss of suitable seedling habitat and disruption of gap-phase succession – some species of vernal herbs root in deep pockets of organic matter or have higher covers at the base of trees or on fallen logs; removal of organic materials, such as logs, may reduce microhabitat availability for some species; canopy gaps can provide new microhabitats for herbs, aren't as dry as open clear-cuts, and aren't as likely to be invaded by r-selected species or exotics; while preservation of small tracts of primary forest appear to be important for maintaining herb diversity, they may not be adequate to preserve diversity of herbs on regional and larger scales; selective cutting may, in some scenarios, be more appropriate than clear-cutting for the maintenance of vernal-herb populations in secondary, mixed, mesophytic forests; it is possible that transplantation of these species may help restore vernal-herb populations of secondary, mixed, mesophytic forest

61. "Natural Resources Conservation Service Conservation Practice Standard: Riparian Forest Buffer." July 2010.

Defines a riparian forest buffer as an area predominantly trees and/or shrubs located adjacent to and up-gradient from watercourses or waterbodies. They have many purposes, including creating or improving riparian habitat, detritus and debris, and shade, and reducing sediment, organic material, nutrients, and pesticides. Includes prescriptive details on how a riparian forest buffer should be designed and implemented. The buffer should be a minimum of 35 ft wide, unless it is in a high nutrient, sediment, and animal waste application area, in which case it should be wider to accommodate for the necessary additional level of protection. The document

also includes things to consider when choosing plants, layout, and size, and notes that plans, specifications, operations, and maintenance are necessary when implementing a riparian forest buffer.

62. *Natural Resources Conservation Service. "Hedgerow Planting for Pollinators & Wildlife: WV Conservation Practice Job Sheet." Apr. 2011.*

Details how to create/maintain hedgerows to provide food and cover for wildlife. Several hedge species are sources of pollen for bees, and some species of plants may provide nesting sites for wood nesting bees. Best results are achieved when there is a mixture of trees, shrubs, grasses, vines, and/or forbs. Hedgerows established for pollinators are a minimum of 25 feet wide and will usually require multiple rows of plants. The plants must provide abundant pollen and nectar resources throughout the season, and shrubs that contain soft pith for wood nesting bees should be considered. Plants that bloom during the same period as adjacent insect-pollinated crops can be excluded. Installation of artificial nest boxes with predator guards can encourage pollinators to utilize a hedgerow.

63. *Snyder, Michael. "Why Are Some Trees Pollinated by Wind And Some by Insects?" Center for Northern Woodlands Education, 20 Apr. 2009, https://northernwoodlands.org/articles/article/why_are_some_trees_pollinated_by_wind_and_some_by_insect_s*

"By contrast, trees that rely on pollination by animals (chiefly insects, but also birds and bats) tend to produce far less pollen in any given flowering period, because pollination is more direct and efficient. The animal-transported pollen also tends to be slightly sticky, less dust-like, and produced later, when the leaves are forming. This approach seems to work better among widely-spaced individuals. There are fewer examples of native non-wind pollinated species. Among the best known insect-pollinated trees are apples, basswood, cherries, black locust, catalpa, horse chestnut, tulip tree, and the willows. As logic would have it, species that rely on insects (mostly bees, wasps, flies, beetles, butterflies, and moths), birds, and bats, tend to have fragrant (sometimes stinky), large, or otherwise showy flowers."

64. *Staley, Joanna T., et al. "Long-Term Effects of Hedgerow Management Policies on Resource Provision for Wildlife." *Biological Conservation*, vol. 145, no. 1, 2012, pp. 24–29., doi:10.1016/j.biocon.2011.09.006.*

Hedgerows provide important habitat and food resources for overwintering birds, mammals, and invertebrates. The authors conducted a factorial experiment on hawthorn hedges to test the effects of cutting frequency and timing of cutting on the abundance of flowers and berry resources. Results from 5 years show that hedgerow cutting reduced the number of flowers by up to 75% and the biomass of berries available over winter by up to 83% compared to monitored uncut hedges. Reducing cutting frequency from every year to every 3 years resulted in 2.1 times more flowers and a 3.4 times greater berry mass over 5 years. If hedges managed under the usual practice of cutting every 2 years were instead cut every 3, the authors estimate that berry biomass would increase by about 40%, resulting in a substantial benefit for wildlife. The authors concluded that uncut hedgerows provide far greater resources for wildlife than cut hedgerows, even those cut under a reduced cutting frequency, but the practical demands of farm management make uncut hedgerows unrealistic. Reduction in the agricultural labor force and the prevalence of autumn sowing result in hedgerows typically being cut in late summer or early autumn after harvest, which removes berry resources before winter starts.

When the hedges in the experiment were cut, the wood was removed from the area. Cutting timing may alter hawthorn physiology and growth patterns. Winter cutting had a detrimental effect on subsequent flower and berry formation on the plots cut every 3 years, but not those cut annually or biennially.

65. *United States, Congress, "Pollinator-Friendly Best Management Practices for Federal Lands." Pollinator-Friendly Best Management Practices for Federal Lands, U.S. Forest Service, 11 May 2015.*
www.fs.fed.us/wildflowers/pollinators/BMPs/documents/PollinatorFriendlyBMPsFederalLands05152015.pdf

Resource that consolidates general information about practices and procedures to use when considering pollinator needs in project development and management of Federal lands that are managed for native diversity and multiple uses. The BMPs are organized under three subject areas: (1) BMPs to improve pollinator habitat, (2) BMPs to protect pollinators when taking management actions, and (3) BMPs to protect and sustain specific pollinator species. In general, managing for pollinators involves protecting, enhancing, or restoring wildflower-rich foraging habitat; providing hive site locations and nest sites for native bees; providing host plants for butterflies; and providing overwintering refuge for other insects. Also lists 8 key considerations when evaluating projects for conserving pollinator habitat: determining the quality of foraging habitat; identifying important pollinator reproduction sites; determining important nesting and overwintering sites; identifying pollinators of sensitive or at-risk plant species on Federal, State, local, or NGO lists; identifying and removing invasive species to improve pollinator habitat; identifying, collecting, and using local, genetically appropriate native seeds; implementing adaptive management; and engaging and informing the public. Page 9 of the document includes information on how woody debris is important to pollinator habitat. Includes as appendices: a memorandum from the Obama administration on federal strategy to promote the health of pollinators; a list of partnerships, programs, and initiatives for pollinators; and a short review of services native plants provide for pollinators.

66. *United States, Congress, "Pollinator Research Action Plan." Pollinator Research Action Plan, Pollinator Health Task Force, 19 May 2015.*
https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/pollinator_research_action_plan_2015.pdf.

Light on scientific information but potentially a good jumping-off point for other resources. Heavy emphasis on honey bees. Lays out current and planned Federal actions to achieve three overarching goals: reduce honey bee colony overwintering mortality; increase the Eastern population of the monarch butterfly through domestic/international actions and public-private partnerships; and restore or enhance 7 million acres of land for pollinators through Federal actions and public/private partnerships. Creates plans for lots of new research – federal, academic, private, and combinations of all. Notes the Integrated Crop Pollination Project (ICP) as a resource developing decision frameworks and models to design forage habitats for managed and unmanaged pollinators in specialty crops. Contains an appendix on web sites with resources and tools for pollinator health.

67. *Williams, Neal M. "Restoration of Nontarget Species: Bee Communities and Pollination Function in Riparian Forests." Restoration Ecology, vol. 19, no. 4, July 2011, pp. 450–459., doi:10.1111/j.1526-100x.2010.00707.x.*

The author surveyed bee communities at five equal-aged (mid-successional) restored sites paired with five reference sites along the Sacramento River, CA, US. Flower availability and bee visitation patterns were also measured to examine the restoration of pollination function. The composition of pollinator communities was distinct in restored sites vs remnant riparian sites. Because differences did not arise primarily from differences in

the composition of the flowering-plant community, there must be other physical characteristics that led to the different pollinator communities, unlikely landscape context. All restored sites lacked a closed canopy in any part of the plot or the larger restoration site, while the remnant riparian sites all had some areas with mature trees. Ground cover at restored sites tended to be composed of grasses interspersed with patches of bare ground and remnant riparian sites had more shrubby vegetation. The difference may be partially explained by bee life-history and other biological traits. Pollination function may be less robust in restored habitats. An examination of interaction networks between bees and plant species found at both restored and remnant riparian sites showed less redundancy of pollinators visiting some plants at restored habitats. Bees were sampled via net collecting and pan sampling (fluorescent yellow, fluorescent blue, white), and only on days with full sun, temperatures above 14 deg C, and with wind less than 2 m/s (at 1.5 m above the ground). On each survey day floral abundance was also assessed within each plot. Average richness, abundance, and evenness among bee species did not differ between restored and remnant riparian sites, but composition of bee communities did. Restored sites showed a subset of bee species from riparian remnant sites, and some species which weren't found in any remnant riparian site. These unique species may have come from fragmented natural areas nearby – patches of weedy vegetation between fields, in temporary fallow land, and in irrigation ditches. Average richness and abundance of flowers did not differ between habitat types. Pollinator visitation patterns at restored sites compared to remnant riparian sites suggest that pollination function was restored although at a reduced level – only 14.7% of visitor/plant interactions were shared among habitat types – although connectance among bee visitors and plants did not differ between site types.

68. *Xerces Society for Invertebrate Conservation. Bring Back the Pollinators.*

A campaign based on four principles: 1) grow a variety of pollinator-friendly flowers to provide the nectar and pollen bees need; 2) provide shelter. Ensure there are nest sites for bees, host plants for caterpillars, and places pollinators can overwinter; 3) avoid using pesticides, especially insecticides, because they are harmful to pollinators; 4) spread the word by talking to your friends and neighbors.

Compiled by Margaret C. Lin, January 2021

This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, McIntire Stennis, under accession number 1023728. Support also provided by the National Institute of Food and Agriculture Renewable Resources Extension Program.

Cornell Cooperative Extension is an equal opportunity, affirmative action educator and employer.