

Review

Mitigating the Effects of Habitat Loss on Solitary Bees in Agricultural Ecosystems

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Abstract: Solitary bees and other wild pollinators provide an important ecosystem service which can benefit both the agricultural economy and the sustainability of many native ecosystems. Many solitary bees, however, are experiencing decreases in their populations and ranges, resulting in an overall loss of pollinator species richness in many areas. Several interacting factors have been implicated in this decline, including increased pesticide use, climate change, and pathogens, but habitat loss remains one of the primary drivers. The widespread conversion of natural habitats into agricultural landscapes has decreased the availability of adequate nesting sites and floral diversity for many bee species. Large monocultures with intensive production systems often cannot support the populations of wild bees (particularly species with short foraging ranges) necessary to ensure adequate pollination of animal-pollinated crops. Diversifying agricultural landscapes through the incorporation of wildflower plantings, as well as the preservation of remaining natural habitats, may offer a solution, as it has been shown to increase both bee diversity and abundance and the pollination of nearby crops. In this review article, we discuss the various effects of habitat loss on solitary bees and different ways to mitigate such effects in order to conserve bee diversity and populations in agricultural landscapes.

Keywords: solitary bees; wild bees; native bees; pollinator; habitat loss; floral diversity; bee nutrition; pollinator decline

1. Introduction

Animal pollinators, and in particular insect pollinators, provide an important ecosystem service, one which globally benefits the diversity of wild plants, the human diet, agricultural production, and the economy [1]. They support many native ecosystems, as around 80% of wild angiosperm species are pollinated by animals, and the majority of these rely on pollination by different species of bees [2]. Crop production, as well, often requires or at least improves with bee pollination, and this is especially noted in certain crops, such as vegetables, fruits, and oils. Overall, around 9.5% of the total worldwide agricultural production is due to the services provided by these insect pollinators [3]. The contribution to agriculture has been estimated to produce 15–30% of the human diet, both from the pollination of food crop plants that are consumed directly by humans and from the pollination of plants, such as alfalfa and clover, that are used to feed livestock [4]. Along with the improvements to the nutrition and diversity of the human diet, there is an economic value to the pollination by bees. In 2009, 11% of the agricultural gross domestic product (GDP) came from crops pollinated by animals [5]. An estimated \$3.07 billion annually in the United States alone comes from the plants pollinated by wild bees, including unmanaged bumble bees and solitary bees [6].

Because of this value of pollination by bees, it is important to maintain their populations and to therefore ensure that adequate pollination continues in both wild and cultivated flowering plants. However, bee pollinators globally are facing problems with declining populations and reduced

biodiversity [7–10]. The majority of the research on both the contributions of bee pollinators and the bee population declines has focused on honey bees (*Apis* spp.), and to a lesser extent bumble bees (*Bombus* spp.), but there is a lack of information on the solitary bees, which make up the majority, over 85%, of the estimated 25,000–30,000 species of bees worldwide [11]. In North America alone, there are around 4000 species of native bees [12], 54 of which are bumble bee species and over 3900 solitary bee species [13]. Western honey bees (*Apis mellifera*) are not a native of North America, but were brought over in 1622 from Europe to the Americas [12,14]. There is no doubt that managed honey bees provide valuable pollination services, but solitary bees have long been overlooked as pollinators of wildflowers and crops. Many growers of bee-pollinated plants could benefit from encouraging a diversity of species and families of bees, beyond just honey bees [15].

Native solitary bees can be more efficient pollinators of certain wild plants and crops than honey bees, and have the potential to enhance crop yields with their pollination services [16]. Many growers rely on solitary and wild bees for pollination in their fruit farms [17,18]. Sweet cherry orchards, for example, had higher yields when pollinated by the blue orchard bee (*Osmia lignaria*) than when pollinated by *A. mellifera* [19]. The native solitary bee, *Anthophora urbana*, and the bumble bee, *Bombus vosnesenskii*, were both able to increase tomato production. Tomatoes are often self-pollinating plants, but when cross-pollinated by wild bees, more tomato flowers developed into fruits [20]. Wild bees may also enhance the pollination ability of honey bees, as was observed in a study on sunflower seed production. They found that the presence of wild bees actually increased the pollination efficiency of honey bees, measured by the number of seeds produced compared to the number of visits by bee pollinators [21].

Native solitary bees can be more effective pollinators of certain flowers than honey bees, in part due to their ability for sonication, the vibration of the bees' indirect flight muscles. Sonication can be used for multiple purposes, including defense warning and nest building, but many native bees, such as *Bombus* and *Xylocopa* species also use it for pollen collection. Flowers that require sonication for pollination, or “buzz-pollinated flowers” are not well pollinated by honey bees, but rely on wild bees [22]. Because of these services provided by solitary bees, it is important to maintain their populations, and to maintain a high species richness of both solitary and social bees. This review focuses on the detrimental effects of habitat loss on wild and solitary bee populations and on developing strategies to mitigate them. In addition, the conservation of solitary bee diversity in agricultural landscapes and enhancement of their pollination services are both briefly discussed.

2. Recent Declines in Native Bee Populations

Many insect pollinators, including species of honey bees and native North American bees have seen recent declines in population in different geographical regions [9,23–28]. Compared to other geographical regions, in North America there has been a better documentation of population declines and loss of species richness in the *Bombus* genus, though there has been evidence for solitary species as well [29]. Surveys comparing the relative abundance and range of several *Bombus* species have found several species to be in serious decline, and that some of the declining species formerly had broad geographic distributions [30]. Some species appear to have become regionally extinct, or at the least extremely rare, in areas where they had been previously caught. For instance, three species, *Bombus affinis*, *Bombus pensylvanicus*, and *Bombus ashtoni*, were all well observed in a survey in the eastern United States in the 1970s, but could not be found in a comparative survey in the early 2000s [24].

The decline of solitary bees, however, has been more thoroughly researched and documented in Europe than in North America and other continents. In the Netherlands and the United Kingdom, researchers observed a loss of diversity and evenness of unmanaged (non-*Apis*) bee populations, with the pollinator populations becoming increasingly dominated by a smaller number of species. They also noted that the species in decline tended to be specialist feeders with lower mobility [31]. Similar results were seen in Belgium and France, and the percentage of declining species was especially high in the *Apidae*, *Anthophoridae*, and *Megachilidae* families of bees (around 58%, 55%, and 25%,

respectively) [32]. Ireland was estimated to have 3% of their native species regionally extinct and 41% threatened or endangered [33]. These trends coincide with overall losses in insect diversity and biomass in many world regions [34,35].

Many interacting factors have been implicated in these declines. Temperature changes, which can be brought on by climate change, have been observed to alter bee development and emergence [36]. Agrochemicals, including insecticides, herbicides, and fungicides, have been implicated as risk factors to pollinators, though there is still a great deal of disagreement on the extent of this threat [37–39]. Parasites and disease can cause harm to social and solitary bees [40–42]. Of the many risk factors, the loss of native habitats, especially when the loss is caused by urban development and to an even greater extent, agricultural intensification, stands out among risk factors as one of the most detrimental to bee populations [43–45].

3. Habitat Loss as a Major Contributor to Bee Population Decline

Habitat loss has become a particular cause for concern as the amount of land dedicated to agricultural use has rapidly expanded since the 1700s, with an estimated 600% increase of the area of grazing land alone. Managed grazing land now takes up around 25% of the terrestrial surface of the planet Earth, which equates to over 33 million km² worldwide [46]. New grazing land for livestock has expanded over several biomes globally, including grasslands, deciduous and evergreen forests, and tropical forests. In North America, heavy grazing by livestock in prairie habitats can cause the grassland to degrade, lose a portion of its floral diversity and become more like a desert [46]. The cultivation of grains and other crops have also undergone an intensification in the past century, in both the yield of the crops and the area of land used to grow them [47]. This agricultural expansion has coincided with, and in many cases caused, the decrease of native habitats used by solitary bees. From 1830 to 1994, the United States experienced up to an 82% to 99% loss of unmanaged tallgrass prairie [48]. Of the prairies that remain, they tend to be too small and too scarce to provide a suitable habitat for the biodiversity they formerly supported [49]. The ranges of many common native bees, both bumble bees and solitary bees, have declined in North America over the past century, as their native habitats, such as the tallgrass prairies, have been largely taken over by land for agricultural use [38,44,48].

3.1. Effects on Nesting Sites of Solitary Bees

Habitat loss can be detrimental to solitary bees due to their particular habitat requirements for adequate nesting sites, floral resources, and the close proximity of these two things. There are a variety of nesting behaviors and materials (i.e., nesting substrates) used by different solitary bee species (Figure 1). Some, such as miner bees (*Andrena* spp.) and many species of sweat bees (Hymenoptera: Halictidae), dig tunnels in the ground [11]. Even within these groups, there is a great deal of diversity of nesting preferences, with different species preferring varying moisture levels, compaction, and grain sizes of the soils [50]. Other solitary bees, like the mason and leafcutter bees (Hymenoptera: Megachilidae), use natural materials, such as mud and leaves, to construct nests within pre-existing cavities on tree trunks or branches. Still others, like the carpenter bees (*Xylocopa* spp.), chew their own holes into wood [11]. This high diversity of nesting preferences suggests a diversity of natural habitats is needed to support a high number of solitary bee species.

Along with adequate nesting sites, a habitat must provide floral resources in order to be suitable for solitary bees. Müller et al. [51] surveyed 41 solitary bee species in Europe and found that each female needed enough pollen to provision around 10–30 brood cells. Depending on the size and pollen requirements of the bees, this could take from one up to hundreds of flowers for each female bee [51]. Bees with a larger body size may also be more susceptible to a decrease in floral resources, because they tend to require more food [51,52]. Modern agricultural trends have the potential to decrease the amount of floral resources available for the bees, with the widespread use of monocultures, especially those in uninterrupted agricultural landscapes, which may not provide adequate nutrition

to support a variety of solitary bees [53]. Native flower plantings provide season-long support to wild bee communities [54,55], and their plantings in monoculture farmland could be helpful in minimizing such effects. Certain bees are highly specialized feeders, only eating the pollen and nectar of a few species or genera of flowers, and may have trouble finding their food source if they cannot feed on the flower of the monoculture crop. Other species feed on a wider variety of flowers, and require some diversity in their diet and in the nutrients they consume [56,57]. Similarly, some studies have shown that by breaking up a purely agricultural area, adding things like hedgerows and uncultivated natural areas, pollinator health and function can improve when compared to pollinators in a strictly monoculture landscape [53].



Figure 1. Leafcutter bees constructing nest in a drilled wood block (a) while ground-nesting solitary bees prefer well-drained patches in bee habitat for nest construction (b). Pictures by N. Joshi.

3.2. Role in Conserving and Propagating Solitary and Wild Bees.

Native, solitary bees require proper nesting sites and plentiful floral resources, and they need them in close proximity to each other. There could be natural areas with all the materials needed for nest construction, but if there are no adequate flowers within the bees' foraging range, then the nest site will go unused. Several studies have been done on the maximum foraging range of various solitary bee species. Generally, they have found that solitary bees prefer to stay closer to the nest and take shorter foraging bouts than social bees, like honey bees and bumble bees. One study, which surveyed 16 solitary bee species, found maximum foraging distances of only 150–600 m [58]. Another found longer foraging distances, but still only 1100–1400 m away from the nest for the three solitary bee species in the study. However, the majority of the individual bees in the study never reached this maximum foraging range. Most resisted traveling more than 300 m away from their nesting sites [59]. Both studies found a correlation between bee body size and foraging range, with larger species able to travel farther than smaller species. When fewer floral resources are available, bees will take longer foraging trips [58], but doing so can have negative effects on the larval bees. By spending more time away from the nest and looking for food, the female bee leaves her nest more vulnerable to predators and parasites [11]. Habitat loss and habitat fragmentation can make it more difficult for solitary bees to find nesting sites and floral resources in close proximity.

4. Floral Diversity: Impacts on Solitary Bee Health

The lack of floral diversity that can occur due to habitat loss can have a detrimental effect on solitary bee health. Solitary bees that are unable to access adequate floral resources show a drop in fecundity and body weight. A study on the European orchard bee (*Osmia cornuta*) found a positive correlation between the weight of the larval provision and the weight of the offspring, meaning that offspring with access to more food tended to grow to a larger size [60]. Similarly, females of the species with a higher provisioning rate also showed an increase in the number of offspring they had [19]. It is not just the size of the pollen provision, however, but also the content of the pollen that can influence bee health and development. When the larvae of the sweat bee, *Lasioglossum zephyrum*, were offered pollen with differing protein contents, larvae that were fed protein-rich pollen grew to a larger size than those who were fed protein-poor pollen [61]. In another example, larvae of the subsocial bee, *Ceratina calcarata*, grew to a smaller adult size and had lower lipid stores when fed a diet with reduced amounts of pollen and nectar [62]. Similar effects have been observed in social bees as well. For instance, bumble bees have a preference for higher quality pollen, with a higher protein content, and will visit flowers that provide this high quality pollen with greater frequency [63].

In addition to affecting body size and development, an adequate diet or lack thereof can affect the susceptibility of many bee species to parasites and pathogens. Most of the research investigating this relationship has focused on social bees, *Apis* spp. and *Bombus* spp., and there is little information on the diseases of native solitary bees. In honey bees (*A. mellifera*), pollen content can play an important role in immune function and detoxification. Pollen, as well as the honey and bee bread made from it, can contain *p*-coumaric acid, an organic compound that can induce and upregulate honey bee genes involved in toxicity and pathogen resistance [64]. Diet diversity from polyfloral pollen was shown to increase glucose oxidase (GOX) activity in *A. mellifera* compared to monofloral pollen. GOX is involved in the sterilization of food for brood, and as such is important for honey bee social immunity [65]. *Apis mellifera* larvae fed a nutritionally poor monofloral pollen diet were more susceptible to the fungal parasite, *Aspergillus flavus* than those that were fed diets supplemented by either polyfloral pollen or dandelion pollen [66]. Similarly, common eastern bumble bees (*Bombus impatiens*) that were infected with trypanosome parasites, *Crithidia* spp., had higher survival rates of the infection when fed nectar with higher sucrose concentrations (30%) and pollen, as opposed to bumble bees fed reduced nutritional diets [67]. Pollen and nectar provide protein and carbohydrates to bee diets, which can influence health and immunity, but can also include secondary metabolites, which can also have an impact on bee interactions with parasites and pathogens. Secondary metabolites are chemicals produced by plants, often acting as defensive compounds to deter herbivorous feeding [68]. Low levels of these compounds can also exist in nectar and can be consumed by pollinators. Some of these secondary metabolites have been shown to reduce parasite loads in *B. impatiens*. This effect was most noticeable with the alkaloid, anabasine, which is produced by *Nicotiana* spp. of plants. Anabasine reduced levels of the parasite, *Crithidia bombi*, by 81% in one study [69], and in another was shown to have no negative effect on the health of unparasitized bees [70]. Solitary bees can also be infected by a variety of viral and fungal pathogens and can be affected by nest parasites, including species of blister beetles (Coleoptera: Meloidae) and cuckoo wasps (Hymenoptera: Chrysididae) [41,71]. The relationship between their diet and infection rates remains under-researched, however.

More research is needed on more species of solitary bees, but these initial findings suggest that both social and solitary bees require high quality pollen that contains an adequate protein content, as well as beneficial organic compounds, including certain plant secondary metabolites. The protein content of bee bread, a mixture of pollen and nectar used to feed bee larvae, can differ depending on the nest's proximity to natural areas. Bees that were able to forage closer to wild grasslands and forests had a higher protein content in their bee bread than those that foraged in farmland areas [72]. Habitat loss can cause solitary bees to be farther from these natural areas, which can lead to a decrease in the protein content of the larval provision. This could have detrimental effects on the size and health

of the larval bees and suggests that many agricultural landscapes do not provide the adequate volume and nutritional requirements of food for many solitary bees.

Floral Diversity Affects Community Dynamics of Solitary Bees

Overall, areas with a higher diversity of flowers, such as natural habitats, have been shown to also have a higher diversity of bees [73,74]. Incorporating diverse floral plantings in an agricultural landscape could enhance ecosystem services of pollinators and other beneficial insects [75,76], and could support bee communities after the flowering period of main crops [77]. The drop in diversity of solitary bees, as they move farther away from these natural habitats, like woods and prairies, is cause for particular concern, because a higher diversity of bee species can have a positive impact on pollination and plant yield. Inversely, a lack of bee diversity caused by the distance from natural areas can have a negative impact on pollination, as was observed by Hoehn et al. [78]. In this study, a greater diversity of bee species was shown to increase seed production in pumpkin plants. There are a few factors that may explain this increase. Bee species differ in the times of day in which they are active, so greater species richness would likely increase the amount of time that a flower is pollinated. Certain bee body sizes are better suited to visit different flower shapes, flower sizes, and parts of flowers. In addition, different species of bees are also known to have a preference for different flower colors. Having a variety of species, and therefore a variety of body sizes, in an area can likewise increase the number of flowers that get pollinated. Greater species richness can increase production overall of some crop plants [78]. Several other studies have found that proximity to natural areas can enhance the diversity and pollination ability of solitary bees in both North America and Europe [38,79–82]. For instance, in a Costa Rican study on coffee bean production, fields that were within 1 km of forest and riparian zone habitats had a higher diversity of both solitary and social native bees, as well as a 20% increase in yield and a reduction in misshapen coffee beans [83]. A similar effect had been observed for watermelon production, where Kremen et al. found that in watermelon fields with a greater proportion of natural habitat within 1–2.5 km, the pollen deposition by solitary bees was enhanced when compared to fields that were farther from the natural habitats [15].

Habitat loss and fragmentation can have a negative effect on bee abundance and diversity, but this effect was greatly ameliorated in areas where some natural habitat remained [84]. The enhanced pollination ability of solitary bees and increases in crop yield due to the presence of a nearby natural area can provide an economic benefit to many farmers of insect-pollinated crops. The conservation of solitary bees is therefore important both for protecting wild ecosystems and agriculture [38,82,83]. Having a greater diversity of species can help make a community more resilient as well. The loss of one species will not mean the loss of the entire ecosystem service, in this case pollination, when species diversity is high [85]. There has been some debate over the degree of competition between managed honey bees and wild bees in North America, and whether honey bees take resources from wild solitary bees and bumble bees [86]. However, both honey bees and wild bees are able to benefit from having an abundance and diversity of floral resources, and especially when they have access to natural habitat and wild angiosperms. Managed honey bees may be more tolerant to areas with poor floral availability, likely due to the intervention of beekeepers who can supplement the bee hives with alternative food sources, but solitary bees tend to be more vulnerable [87]. The conservation and management strategies for both honey bees and native bees in North America may be similar. By providing more floral resources, the populations of both groups can benefit.

5. Recommendations and Implications

Given the detrimental effects that habitat loss can have on solitary bees, the preservation of the remaining natural areas could also preserve the populations and species richness of the solitary bees. For habitats such as the tallgrass prairie in the central United States, conservation is especially important, because the tallgrass prairie has been so reduced in area over the past three centuries [48]. Currently temperate grasslands and savannas remain some of the least protected habitats [88]. Major

threats to these habitats include overgrazing by livestock, droughts, and tree encroachment [46]. Prevention of encroachment by wood plants and trees in grasslands and savannas would help with their preservation [48]. Such habitats can provide both nesting sites and food resources for a variety of bees, so their conservation would also help maintain the biodiversity of bees in these areas.

For areas that have already undergone a great deal of habitat loss and agricultural intensification, landscape management can help to enhance solitary bee diversity and promote pollination [89]. Miniature natural habitats can be added to agricultural landscapes in the form of native flower plantings or floral strips (Figure 2), and in other forms, such as shelterbelts, and hedgerows, which can provide nesting sites and wind breaks when planted on the edges of crop fields and grazing lands [87,90].



Figure 2. Establishment of floral resource plantings comprised of diverse native flowering plants for bees and other pollinators near crop fields (a) and high tunnels (b). Pictures by N. Joshi.

The management of natural areas for ecosystem services is still poorly understood and is not done often or well [91]. More information is needed to strike a balance between the land reserved for ecosystem services like pollination and land used for agriculture, and to know how much natural land is needed for adequate pollination [15]. A stable population of the pollinating bees can provide an economic benefit, so natural habitats are worth the investment to ensure the ecosystem service continues [92]. This balance between the ecological and economic benefits of adding natural habitats and the initial financial costs of establishing native plants has been more thoroughly researched in California. There, schemes to establish hedgerows of native trees, shrubs, grasses, sedges, and rushes, have been shown to improve several ecosystem services, including soil erosion control, enhanced water filtration and water quality, and increased species richness of beneficial arthropods [93,94]. These hedgerows also have the potential to serve a great benefit for more vulnerable pollinator species, particularly those with specialist diets, lower mobility, and specialized nesting site requirements [95]. Such restoration schemes are still not often used in the United States due to the upfront costs of establishing such habitats and the concern that such schemes will not see a financial return on investment. These upfront costs can be high, with the estimated cost of a 300 m hedgerow in California to be \$4000 [93]. A few years after establishment, however, natural plantings often require little upkeep [94], especially when compared to conventional field edge management strategies of frequent mowing and herbicide treatments, which can also be financially costly [93,96]. One economic cost-benefit model estimated a return on investment within 5 to 16 years, depending on the ecosystem service requirements of the area [93]. This would likely vary by region and by local landscape conditions, and is worth investigating on a local level.

Poor nutrition is one of the main concerns of the negative effect that habitat loss can have on solitary bees, so providing more floral resources has become an effective management strategy. In Europe, several farms have adopted floral provisioning schemes and planted wildflowers alongside their fields. Such schemes can provide a greater amount and variety of floral resources for the bees, though there are several considerations to keep in mind when selecting flowers, including seed costs, pollinator floral preferences, regional growing conditions, and bloom period [97–99]. The cost of buying wildflower seeds is one of the major factors determining whether a floral provisioning scheme will be implemented at all. Lower cost provisions are more likely to receive support and can also ensure that more areas of land can potentially be planted [97]. Another economic concern for wildflower plantings on field margins is the loss of land area that would have otherwise been used for crop plantings. It is also important to select field margins that will not serve as a secondary host of arthropod pests for the crop fields [100]. These plantings have been shown to improve bee species richness in several world regions, however. Planting native, bee-preferred plants helped both solitary and bumble bee populations in Italy [101]. In North America, a study that compared plots with wildflower mixes to unmanaged weedy plots, found that the wildflower mixes in all the observed regions (Florida, Michigan, and California) increased the abundance and species richness of wild bees when compared to the control [55]. Flat monoculture landscapes are also a cause for concern, so the use of crop diversification could help maintain bee diversity [87]. Aside from actively planting wildflowers, there are some simpler and potentially more cost-effective measures, as well. Mowing less frequently has been shown to improve pollinator abundance in residential landscapes, but may be applied to agricultural landscapes. Common garden weeds, like dandelion and clover, can provide high quality forage for many bees when allowed to grow longer and to flower [102]. Again, however, it is important to monitor such areas for detrimental weeds and alternative host plants that may interfere with nearby crop production. Floral plantings directly along crop field margins may offer the greatest benefit to crop pollination, but unused areas, such as road verges and powerline easements, may also benefit pollination if planted with wildflowers or mowed less frequently [96,103,104]. Finally, wildflower provisioning can have additional benefits to local ecosystems and crop yields, besides pollination. Such plantings can increase the population density of natural predators, such as spiders and lady beetles, which feed on crop pests, and have been shown to reduce pest populations of soybean aphids [75,105].

Supplementing habitats with different nesting substrates could be helpful in propagation of solitary bees in agricultural ecosystems. Different types of nest-box designs [106–109] and supplementations are used for mason bees and leafcutter bees (Figure 3). Adding artificial habitats to an area could attract and maintain solitary bees, particularly cavity- and tunnel-nesting bees. Many such “bee hotels” have become available in recent years, though they are often designed to attract a variety of native and non-native bees by including holes or tubes of varying widths [110]. This can raise concerns of increasing parasite and pathogen spread among residents of the artificial nests [111]. Appropriate nesting substrates and nest liners for the mason bees and other tunnel-nesting bees are important to provide protection from different pests [112]. Soil amendments in bee habitats could be helpful for ground-nesting bees, as these bees construct their nests in well-drained soils [113]) and soils with differing textures and grain sizes [50]. Unlike tunnel-nesting bees, artificial nests for ground-nesting bees may not be as effective, however, and could remain empty [101]. The development of species-specific artificial nesting substrates could help in the conservation and propagation of wild and solitary bees in different ecosystems, and future research should continue to design and develop cost-effective and durable nest substrates for different species of solitary bees.

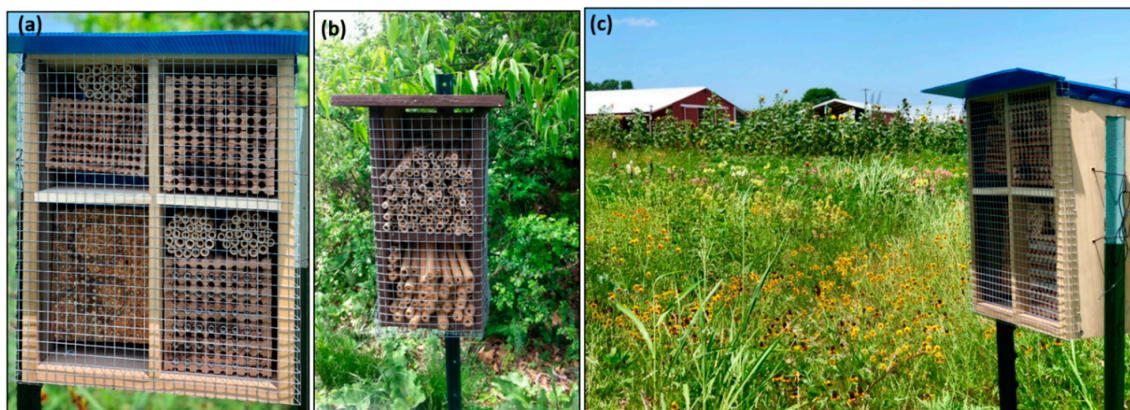


Figure 3. Different types of nest supplementations for mason and leafcutter bees (a,b) and deployment of a nest box (also known as Bee Hotel) in bee habitat (c). Pictures by N. Joshi.

Because much of the research on pollinators has focused heavily on the social bees, more information is needed in order to fully understand the impact that habitat loss is having on the solitary bees. It is clear that solitary bees have distinct and varied habitat requirements that are not always met in heavily managed agricultural areas, and that both pollinator function and species richness benefit from a close proximity to natural areas [15,80,83]. It would be beneficial to have more information on the relationship between the ecosystem service provided by the bees and the amount of natural habitat they require [15]. In addition, establishing region-specific baseline information on wild bee diversity and abundance would be helpful in documenting the impact of habitat loss on the communities of these bees. Wild bees are more difficult to survey than managed bees, but given the importance of these bees to the pollination of wildflowers and crop plants, their populations are worth monitoring and protecting. Developing and implementing coordinated research projects on regional and global scales would be an important step in this direction.

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