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REVIEW

Amount, distance-dependent and structural effects of forest patches on bees in agricultural landscapes

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Abstract

Background: The growing human population and the need for more food in the world have reduced forests and turned them into agricultural land. Many agricultural products are dependent on pollinating bees, so it is possible to increase crop production by increasing the population of bees in agricultural landscapes and preventing further deforestation. In agricultural landscapes, bees use forest patches as nesting habitats and, therefore, are highly dependent on these patches. Therefore, by creating new forest patches within agricultural fields, we can increase the pollination rate, and thus the crop production. In this regard, understanding the role of forest patches and their effects on bee populations is a key step in successfully implementing the patch creation strategy. To determine the effects of forest patches on bees and pollination services, we reviewed 93 articles examining the effects of forest patches on bees in agricultural landscapes. We divided these effects into three categories based on the sampling method: (1) distance-dependent, (2) amount, and (3) structural effects.

Methods: We searched for published studies related to the effects of the forest patches on bees in agricultural landscapes using the ISI Web of Science. We conducted our search from May 1991 to May 2021 using the following search string keywords: forest fragment, forest patch, forest fragmentation, pollination, and bee.

Results: Approximately, 79% of studies showed that by increasing the distance (up to 2 km) from forest patches, regardless of the type of species, the type of agricultural product around the patches, the size and number of patches, the bees' diversity and abundance decrease. Approximately, 76% of the studies showed that the presence of forest cover within a radius of 2 km from the target sites has a positive effect on bee populations. Our data also show that larger forest patches maintain a larger population of bees than smaller ones.

Conclusion: It was not clear what percentage of a landscape should be covered by forest or how much habitat was sufficient to maintain a viable population of bees. Therefore, we suggest future studies to find the thresholds of forest amounts below which the bee population is rapidly declining.

Keywords: Agricultural landscapes, Bees, Forest patches, Pollination

Introduction

In recent years, declining pollinator populations as a global concern [123] have led to more research into identifying their threats and the consequences of their reduction in natural and agricultural systems. Approximately, 88% of angiosperms [81] and 87 of the 115 most important food products require pollinators [57]. Klein et al. [57] claim that at least 35% of the world's food products

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are directly dependent on pollinators, and therefore these species are of considerable economic importance. Among pollinator species, bees are known as the most important pollinators [127]. Farmers often use honeybees to pollinate their agricultural products but recent declines in the population of these species [87] have led to more attention being paid to wild bees. In the absence of honeybees, wild bees can increase agricultural products by pollination [43]. Wild bees account for 9.5% of the total agricultural products in the world [41].

Due to the growing human population, it is necessary to increase agricultural production by 70% by 2050 [21]. The second goal of the Sustainable Development Goals (SDGs) is improving nutrition and promoting sustainable agriculture for achieving food security and consequently ending hunger [6]. These goals would need more arable land in agricultural landscapes which may lead to the deforestation process [54]. Agricultural production is not only dependent on soil fertility, water quality, and pest regulation but also is related to biodiversity such as the presence of pollinators in agricultural farms [11]. Crop pollination by bees is one of the well-recognized ecosystem services in agricultural landscapes, which plays a key role in global food production [9, 88]. Therefore, we can improve production per unit area through increasing pollination rather than expanding agricultural land.

Recent declines in the honeybee population, along with increasing demand for pollination services in urban, agricultural, and natural environments, have led to strategies to increase and attract pollinators to these areas. Creating new natural patches in suitable places can increase ecosystem services in a landscape [37]. In landscapes that experienced drastic changes and the remaining habitats are highly fragmented, creating new habitat patches can provide a new habitat alongside the remaining patches [29]. For example, restoring a forest habitat to make a connection between the remaining patches improves functional diversity [28]. To increase pollination in agricultural landscapes which consist of two ecosystems, agriculture and forest, it is critical to understand how wild bees are affected by habitat quality and landscape structure [83, 116]. Investigating the effects of forest fragmentation on pollination can be a useful guide in optimizing a landscape to increase pollination service [70].

The presence of nesting habitat and floral resources is of great importance for bees. [83, 94]. Moreover, the proximity of these habitats to each other provides favorable conditions for pollinators because they spend less energy to find food and take it to the nest [60]. Therefore, the distance between nesting habitat and feeding has a significant effect on the presence of pollinators in a land landscape [34, 94, 112]. Therefore, in the study of pollinators, special attention should be paid to the structural patterns of the landscape [91, 116]. The arrangement of suitable nesting patches and the ability of pollinators to move from these patches to surrounding farms affect the pollination rate in agricultural landscapes [74]. In addition to nesting habitat, adequate floral resources should be available to pollinators in a landscape [60]

In agricultural landscapes, pollination service depends on the movement of pollinators from nesting habitats (such as forests) to foraging habitats (such as farms) [94]. In these landscapes, forest fragments mostly serve as nesting habitats for bees, especially above-ground nesting species. About 30% of the more than 20,000 known bee species in the world are above-ground nesting [40]. For example, bumblebees, honeybees, and stingless bees are eusocial and are among the above-ground nesting bees [8]. Stingless bees are the most diverse social bees, and many of them depend on natural cavities to form colonies [104]. In natural environments such as forests, they nest in tree hollows. Since wild bees are highly dependent on forest patches as a nesting habitat in agricultural landscapes [83, 92], it is possible to attract more populations from pollinators by creating new forest patches. How many patches are needed and how they should be arranged in a landscape is the most important question in this area [20]. However, little attention has been paid to the location and size of the new patches, and more studies are needed in this area [73]. Therefore, it is necessary to determine the role of forest patches and their effects on bee populations in agricultural landscapes. Other important questions in this regard are (1) how do the structural aspects of forest patches, including the number, area, shape, isolation, and connectivity, affect the population of bees? (2) How far can forest patches supply pollination services by supporting bee populations? The present study aims to find answers to the mentioned questions based on previous studies. We reviewed 93 articles examining the effects of forest patches on bee populations and pollination services and presented the key results and details of these studies in three separate tables.

Methods

We searched for published studies using the ISI Web of Science. We conducted our search from May 1991 to May 2021 using the following search string: (forest fragment* OR forest patch* OR forest fragmentation*) AND (pollination* OR bee*). Nearly, 1865 articles were obtained, leaving 797 unique articles after removing duplicate articles. We were looking for studies that examined the effects of forest patches on bees in agricultural landscapes. In other words, the landscape around the forest patches was covered mostly by farms.

We found 100 articles examining the different effects of forest patches on bees in agricultural landscapes. We divided these effects into three categories based on the sampling method: (1) distance-dependent effects: this group of studies answers the question of what changes in bee population occur with increasing distance from forest patches in the agricultural landscapes. The sampling method of bees in these studies is based on plots or transects that examine bees in the farms under study at different distances from forest patches. The first sampling site is near the forest and the last site is at the farthest distance from the forest, (2) effects of forest amount: these studies answer the question of how the amount of forest cover around the target sites affects the bee population. In this type of study, bee populations are examined in several plots and then their relationship to the forest amount around the plots is evaluated in different buffers or scales, and (3) structural effects of forest patches: in this type of study, plots or transects are placed inside forest patches (not on farms). One or more forest patches are sampled and the relationship of the bee population within these patches with the structural features of the patches such as isolation, connectivity, number, area, shape, and complexity of patches is evaluated. Details of the studies of each of the mentioned categories are presented in three separate tables, which contain 36, 32, and 33 articles (93 unique), respectively.

Results

Distance-dependent effects of forest fragments on bees

Table 1 shows the country, the number of forest patches (NP), their area (ha), the distance of sampling sites or plots from forest patches (proximity), type of pollinators, matrix around the patches, and key results of studies that have examined the distance-dependent effects of forest patches on bees' populations. This table presents 36 articles, most of which (22%) have been conducted in Brazil. Some of these studies have reported the number of forest patches and their area in landscapes understudy, but most of them did not provide details of forest patches, so we used a dash as a lack of information. The number of forest fragments reported in these studies varies from 1 to 14 (on average 4 patches). The area of these fragments varies from 0.3 hectares to 65,000 hectares, with an average of 3100 hectares.

The proximity column shows the distance between the plots or sampling sites and forest patches. Some studies have considered only one distance, but others have examined several distances. In the proximity column, we have reported the nearest and farthest distance between the sites and forest patches. Therefore, in this column, the first number indicates the distance that the first site was examined and the second number indicates the farthest distance. These distances vary from 0 to 30 km of forest patches, with an average of 1900 m. Approximately 83% of these studies consider the maximum distance from forest fragments to be less than 2 km. Some studies have not presented the details of the understudy species. However, social bees such as honeybees, bumblebees, and stingless bees are seen in 54% of these studies. For studies that have identified a large number of native species, we used the term "Native bees", which includes all species except honeybees. The matrix column shows the land cover around forest patches, of which 27% of the studies have examined landscapes with a matrix covered by coffee products.

Our data show that 75% of studies emphasized the positive effects of forest patches on pollinating bees at all distances. In other words, 75% of studies, regardless of the number and area of patches, the type of species, and the landscape matrix, have found that by increasing the distance from forest patches in agricultural landscapes, factors such as species richness and abundance, species diversity, pollen deposition, visitation rate, agricultural production, pollination success, and pollinator specialization decrease. However, 15% of total studies found that with increasing distance from forest fragments, species richness and abundance, and β-diversity increased, and factors such as parasitism, and mortality rate at the margins of forest patches increased. Approximately, 9% of studies have found no relationship between forest patches and bees. In the case of honeybees, the results of some studies are inconsistent. For example, some studies have suggested that honeybee populations decrease with increasing distance from forest patches [25, 77, 100]. However, Brosi et al. [19] found that at the forest edges, honeybees made up only 5% of the individuals sampled whereas away from forests, they increased to 45%. Bravo-Monroy et al. [14] also showed that in samples far from the forest, honeybee abundance decreased significantly.

Effects of the forest amount on bees

Table 2 shows the details of studies that have examined the effects of forest cover around plots or sampling sites on bees. This table details 33 articles, 27% of which were conducted in Brazil, which has the highest percentage compared to other countries. The buffer column shows the radius (m) around sampling sites. Some studies have considered only one scale (buffer) while others have considered multiple scales. In studies performed on multiple scales, the first number of each row in the buffer column shows the first scale and the second number shows the maximum radius studied. The radius around the sample sites varies from 25 m to 15 km in the studies reviewed in the present study with an average of 1350 m. Approximately, 75% of these studies consider the maximum

Table 1 Country, number (NP) and area (ha) of forest patches, proximity to the patches (m), type of pollinators, matrix around forest patches, and key results of studies that have investigated the distance-dependent effects of forest patches on bees

References	Country	NP	Area	Proximity	Pollinator	Matrix	Key results
[53]	USA	8	3–215	16–324	Honeybee; bumblebee	Farm	Pollination did not have a significant relationship with distance from the forest
[62]	USA	–	–	1000	Native and honeybee	Watermelon	Pollen deposition by native bees was significantly lower at far farms (those surrounded by < 1% natural habitat)
[58]	Indonesia	–	–	0–900	Native bees	Coffee	By increasing distance from the forest edge, social bee abundance decreased. In contrast, social bees' densities increased
[93]	Costa Rica	3	46–111	50–1600	Native and honeybee	Coffee	Visitation rate, pollen deposition, and bee richness were higher near (100 m) forest fragments
[31]	Brazil	–	–	1000	Native bees	Coffee	An increase (14.6%) was observed in farms near the forest
[95]	Costa Rica	2	60–100	50–1600	Native and honeybee	Coffee	Bee richness, visiting rate, and pollen deposition decreased significantly with increasing distance from forest patches
[95]	New Zealand	–	–	0–111	Native and honeybee	Kiwifruit	Visitation of all non-honeybee visitors per flower was significantly higher for orchards near native vegetation
[95]	USA	–	–	100	Native bees	Almond	Despite the proximity of orchards to natural habitats, there was no substantial visitation by native species
[121]	Ecuador	–	–	100–500	Cavity-nesting bees	Rice and coffee	Forest distance correlated positively with bee species richness
[25]	Argentina	–	–	0–1000	Native and honeybee	Grapefruit	By increasing the distance from the forest, visiting frequency decreased. At distances greater than 500 m from forest fragments, honeybees decreased significantly
[59]	Indonesia	–	–	0–1415	*Megachilidae*	Arable land	By increasing the distance from the forest, the total number of bees decreased
[56]	USA	–	–	2000	Ground-nesting bees	Sunflower	More abundant and diverse communities of bees were found nesting at farms with patches of natural habitat nearby than farms that were far away from natural habitat (having < 25% of forest cover in a radius of 2 km)
[126]	USA	–	–	500–1500	*Osmia lignaria*	Farm	By increasing distance from forest offspring reduction increased
[19]	Costa Rica	1	230	0–1500	Native and honeybee	Farm and pasture	Near the forest, honeybees accounted for 5% of the total samples, while stingless bees accounted for 50%. As the distance from the forest increased, *meliponines* decreased to 20% and honeybees increased to 45%
[100]	Kenya	–	–	0–5000	Honeybees	–	At distances of less than 1 km from the forest, the amount of honey produced was doubled that of the hives located at a distance of 3 km
[63]	India	–	0.3–200	10–500	Native and honeybee	Coffee	Distance from forest patches did not affect pollinators
[16]	Mexico	1	15	1–400	Euglossine	Coffee	By increasing the distance from the forest, euglossine abundance decreased
[12]	India	–	–	1400	Social bee	Coffee	By increasing the distance from the forest, the total visitor abundance decreased in rain-fed agroforests
[77]	Argentina	–	–	5–1000	Honeybee	Soybean	By increasing the distance from the forest, total visitation rates decreased

Table 1 (continued)

References	Country	NP	Area	Proximity	Pollinator	Matrix	Key results
[2]	Brazil	2	900–1200	100–1000	Euglossine	Pasture	By increasing distance from forest, abundance, richness, and diversity of orchid bees decreased
[14]	Spain	1	40	500–1800	Honeybee; native bees	Farm	Honeybee abundance can increase with greater distance from the forest
[109]	Thailand	10	3.6–650	20,000	Stingless bees	Orchard	Pollination success in near farms (< 1 km) was enhanced substantially by proximity to the forest than far farms (> 7 km)
[52]	USA	–	–	0–1000	Native and honeybee	Orchard	By increasing the distance from forest patches, the number of bee visits to apple flowers decreased
[30]	Brazil	1	2176	250–500	Cavity-nesting bees	Farm	At the forest edge, parasitism and mortality were more observed
[49]	Brazil	–	–	1500	*Apoidea*	Coffee	Reducing yield gaps and higher biodiversity were found in farms near the forest
[105]	Brazil	1	0.6	600–4000	*Xylocopa*	Passion fruit	By increasing the distance from the forest, total visitation rates of *Xylocopa* decreased
[108]	Thailand	10	360–65,000	50–30,000	Stingless bee	Orchard	At sites near (< 1 km) the forest, the average number of visitor interactions was higher
[22]	Indonesia	–	–	200–1000	Native bees	Cucumber	In farms near (< 200) to the forest, pollinators were significantly lower compared to farms far (> 1000) from the forest Distance from the forest did not affect the productivity of cucumbers
[71]	Brazil	–	–	500–1500	Stingless bee	Mixed	By increasing distance from forest, Stingless bee richness decreased regardless of body size. In contrast, stingless bee body size increased
[86]	Brazil	14	1–39	500	Native bees	Pasture	By increasing the distance from the forest, β-diversity increased
[107]	Estonia	–	–	2000	Bumblebee	Farm	The species richness and abundance were higher in the margins next to the forest compared to the margins next to open habitats
[32]	Nepal	–	–	100–2100	Honeybee; solitary bees	Mustard	By increasing the distance from the forest, diversity measures decreased
[46]	Brazil	–	–	400	*Meliponini*	Coffee	By increasing distance from forest, bee richness and abundance decreased. Bee abundance decreased only when the coffee cover dominated the landscapes matrix
[50]	Argentina	–	1–15	0–200	Native and honeybees	Soybean	By increasing distance from forest, pollen deposition and total visitation rates of native bees decreased
[99]	Mexico	–	–	1000	Native bees	Soybean	The presence of preserved patches contributes to the richness and the abundance of bees, due to the maintenance of wildflowers and ruderal plants in patches next to the crop fields, providing a continuous source of pollen
[125]	Thailand	–	–	1500–15,000	Stingless bees	Orchard	By increasing the distance from the forest, pollinator specialization decreased

radius around the sampling sites to be 2 km. Social pollinators such as honeybees, bumblebees, and stingless bees are studied in 53% of the studies.

Approximately, 67% of the studies have reported that regardless of the species under study, the radius, and the matrix around the sampling sites, the presence of forest cover around the sites has positive effects on the bee richness, abundance, and visiting rate. For example, Ferreira et al. [38] claim that forest cover is the most important factor to increase bee abundance and richness. However,

Table 2 Country, buffer (m), type of pollinators, matrix around the sampling sites, and key results of studies that have examined the effects of the amount of forest cover in a landscape on bees

References	Country	Buffer	Pollinator	Matrix	Key results
[42]	Spain	10–100	Honeybees	Pasture	By decreasing forest cover, fruit set and the number of developing pollen tubes per flower decreased
[117]	Canada	250–1500	Native bees	Corn and soybean	Only at the buffer of 750 m from the forest, bee abundance and richness were positively correlated with the forest cove
[19]	Costa Rica	0–1500	Native and honeybee	Farm and pasture	By increasing forest cover proportion at scales from 200 to 1200 m, *Meliponine* richness increased
[128]	USA	500–3000	Native bees	Farm	Forest cover did not affect crop visitation by wild bees
[20]	Costa Rica	200	Native and honeybee	Farm and pasture	By increasing forest cover proportion, tree-nesting *Meliponines* increased while honeybees showed opposite patterns
[17]	Costa Rica	400	Stingless bees	Farm	Forest cover proportion positively affected *Meliponine* richness and abundance
[119]	Japan	500–4000	*Apis cerana*	Farm	Forest cover proportion within the 1500-m buffer positively affected *A. cerana* abundance in the farms
[15]	Germany	250–2000	Native and honeybee	Wild cherry	Forest cover proportion did not affect bees
[115]	Canada	120–2020	Native and honeybee	Farm	Forest cover proportion negatively affected the total number of species and the number of interaction links between plant and pollinator at buffers of 1520 and 1620 m, respectively
[51]	USA	250–1000	Bumblebee	Mixed	Native species richness was significantly lower in landscapes with greater riparian forest cover
[97]	Mexico	1700	*Frieseomelitta nigra*; *Apis mellifera*	Plantation	Forest cover proportion positively affected bee diversity and abundance on plantations
[129]	Canada	400	Native bees	Grassland	Forest cover proportion did not affect bees
[103]	Brazil	250–2000	Euglossine	Soya, and maize	Forest cover proportion did not affect bees
[101]	Brazil	300–2000	Native bees and honeybee	Coffee	Forest cover proportion positively affected native bee abundance, richness, and diversity at all buffers Forest cover proportion at the 300 m scale negatively affected honeybee abundance
[26]	Switzerland	500	*Osmia bicornis*	Farm	Forest cover proportion did not affect the abundance of *O. bicornis*
[113]	Brazil	250–2000	Euglossine	Water	Forest cover proportion positively affected bee richness within a buffer of 250 m
[39]	Brazil	750–3000	Native bees	Tomato	Forest cover proportion positively affected the abundance of all pollinator groups
[64]	Mexico	200–1000	Native bees	Farm	Forest cover proportion positively affected bee richness, particularly species of the family *Apidae*
[102]	Brazil	250–2000	Solitary and honeybee	Soya, and maize	Forest cover proportion negatively affected the abundance of solitary bees at both 1000 and 1250 m scales
[24]	Brazil	500–1000	*Trigona* spp.	Farm	Forest cover proportion positively affected bee visitation rate
[85]	India	100–2000	Honeybee	Coffee	Positive effects of agroforests, forest fragments, and land cover heterogeneity on the presence and number of nests
[124]	Mexico	250–2000	Native bees	Soybean and maize	Polycultures farms that had the greatest proportion of surrounding forest cover showed the highest bee richness
[71]	Brazil	500–1500	Stingless bees	Mixed	Forest cover proportion negatively affected stingless bee body size; mean community body size was larger in areas with greater amounts of deforestation, and smaller in areas with less deforestation
[72]	USA	500–5000	Native bees	Cornfields	Forest cover proportion negatively affected bee abundance but positively affected bee richness

Table 2 (continued)

References	Country	Buffer	Pollinator	Matrix	Key results
[38]	Brazil	25	Native bees	Deforested areas	Forest cover was the most important factor to increase bee abundance and richness
[35]	Guatemala	300–2000	Bumble and stingless bees	Corn, green bean	By increasing forest cover proportion, bumblebee abundance increased
[27]	Costa Rica	200	Euglossine	–	Forest cover proportion positively affected orchid bee visitation
[125]	Thailand	1500–15,000	Stingless bees	Mixed fruit orchards	Forest cover proportion positively affected stingless bee richness and abundance (< 2 km)
[7]	France	500–3000	Native and honeybees	Orchard	Forest cover at 500 m increased most of all wild hymenopteran abundance and, while forest cover at 3 km promoted average abundance including the domestic honeybee
[33]	USA	250–1000	Native bees	Lowbush blueberry	Bee abundance and richness decreased in cover types with few floral resources such as coniferous and deciduous/mixed forest
[111]	Germany	250–3000	Native and honeybee	Mixed	At 750 m scale, forest cover proportion positively affected bee richness and abundance of solitary bees whereas bumblebees and honeybees did not respond to landscape context at these scales Forest cover proportion negatively affected honeybees at a radius of 3000 m
[96]	Brazil	400–1000	Native bees	Forest	Forest cover proportion negatively affected the functional richness of reproductive plant attributes
[107]	Estonia	2000	Bumblebee	Farm	Forest cover proportion increased bumblebee richness and abundance

15% of the studies reported the negative effects of forest cover on bee populations. For example, Miljanic et al. [72] found that the percent of forest cover had negative relationships with bee abundance, but positively affected bee richness. Saturni et al. [101] also found forest cover positively affected bee diversity, richness, and abundance. However, at the 300 m scale, forest cover negatively affected honeybee abundance. Eighteen percent of the studies also found no link between bees and forest cover.

Structural effects of forest fragments on bees

Table 3 details the studies that examined the effects of size, isolation, shape, fragmentation of forest patches on bees. Tables 1, 2 provided details of studies that examined the effect of forest patches on the surrounding landscape, i.e., agricultural farms, while Table 3 provides studies that examined the population of bees within forest patches, not the surrounding landscape. This table presents 31 articles, 29% of which have been done in Brazil, which has the highest proportion compared to other countries. The number of forest patches studied in these studies varies from 2 to 30 with an average of 11 patches. The area of these patches varies from 0.01 to 1 million hectares. Most of the pollinators studied in these articles are from the euglossine tribe (28%). The isolation column shows the distance between forest fragments in kilometers, which varies from 0.05 to 500 km.

Twenty-three articles have examined the effects of forest patch size on the bee's population within the patches. Some of these studies have found that larger patches support a larger population of bees, in other words, with decreasing the size of forest patches, bee abundance and richness decreases or [3, 5, 18, 20, 23, 45, 47, 48, 82, 106, 114]. However, some studies have shown that small patches support more species abundance and richness than large patches [1, 47, 68, 122]. Some studies have also found that the size of forest patches does not affect bee populations [36, 65, 79, 98, 110], and others claim that the capacity of small patches to support pollinators is the same as that of large ones [78, 118, 130]. The shape of forest patches also affects the presence of bees. For example, Knoll and Penatti [61] showed that there is a high negative correlation between the bee abundance and the forest shape index. Lázaro et al. [66] also found that patch complexity negatively affected the overall number of pollinator visits.

Table 4 summarizes the results of Tables 1, 2, 3. This table briefly shows that most studies related to the effect of forest patches on bee diversity have been conducted in Brazil. In addition, more than 79% of studies have considered distances less than 2 km to examine the amount, distance-dependent, and structural effects of forest cover on bees. Most of the forest patches also had a size of more than 100 hectares. More than 63.8% of the studied

Table 3 Country, number (NP) and area (ha) of forest patches, type of pollinators, matrix around forest patches, isolation (km), and key results of studies that have investigated the structural effects of forest patches on bees

References	Country	NP	Area	Pollinator	Matrix	Isolation	Key results
[4]	Argentina	8	0.5–480	Native and honeybee	Cornfield	–	By decreasing patch size, the frequency and richness of native bees declined but the relative numbers of honeybees increased. Honeybees visiting were negatively correlated with individual trees
[120]	Brazil	2	50	Euglossine	–	–	Euglossine bees moved over cleared areas in search of fragrances
[78]	Panama	10	1–1500	Euglossine	Mixed	100–500	Euglossine bees recorded on islands were visitors from mainland sites and were equally frequent in fragments and continuous forest
[68]	Brazil	8	1–50,000	*Bombus brasiliensis*	Farm	4	Patches maintain greater richness and frequency of floral visitors than continuous sites
[20]	Costa Rica	22	0.25–230	Native and honeybee	Farm; pasture	500	Tree-nesting *Meliponines* were correlated with larger patches, smaller edge: area ratios. Honeybees showed opposite patterns
[122]	Chile	5	2–600	Native bees	Pine plantation	–	Small patches had higher species richness than continuous forests
[18]	Costa Rica	22	0.25–230	Euglossine	Pasture	0.5–19	Euglossine bees' abundance was significantly positively correlated to forest patch size, negatively related to forest shape. Richness was negatively related to fragment area, and not related to fragment isolation
[47]	Spain	6	2–140	Native and honeybee	Farm	1–20	Large patches supported a greater flower visitor diversity, but small patches tended to have higher insect visitation rates
[79]	Brazil	9	1–354	Euglossine	Farm	> 100	Fragment size or ratio area/perimeter did not affect the abundance and richness of euglossine bees but the size of core areas positively affected them
[131]	Switzerland	–	–	*Chelostoma florisomne*; *Hoplitis adunca*	Farm	–	Forests covering a distance of up to 480 m were crossed by *Chelostoma florisomne*
[23]	Mexico	14	0.07–24.9	Native bees	Pasture	2	Patch size positively affected bee richness and diversity
[130]	Mexico	–	–	*Euglossa dilemma*	Farm	130–200	Bee populations forest remnants were neither differentiated from nor had less genetic diversity than, populations in near-continuous forest separated from 130 km of agricultural lands
[1]	Brazil	9	2–18	Euglossine	Pasture; tomato	0.05–135	The smallest forest patch had the highest abundance of bees
[61]	Brazil	4	287–94,000	Euglossine	Coffee	–	Forest shape index negatively affected euglossine abundance
[5]	Brazil	3	100–280	Euglossine	Pasture	3	The largest fragment was the main source of the observed variation in species richness and abundance

Table 3 (continued)

References	Country	NP	Area	Pollinator	Matrix	Isolation	Key results
[82]	Tanzania	6	–	*Megachile*	Tea	–	Continuous fragments had a higher diversity of pollinators than forest patches
[48]	Australia	4	0.15–30	Honeybee	Farm	–	Honeybee abundance and pollen deposition were lower in small patches
[36]	New Zealand	15	0.01–1,000,000	Bumblebee	Grassland	–	Patch area did not affect variation in the abundance or biomass of bumblebees
[45]	Brazil	5	3–484	Native bees	Soybean	20	Patch size positively affected the abundance of *Apinae* and oligolectic bees and negatively affected the richness of *Augochlorini* bees
[114]	Canada	3	7–350	*Andrena*	Forest	–	Two small fragments had higher reductions in reproductive output than the continuous (350 ha) fragment
[10]	Ethiopia	–	4–100,000	Honeybee	Coffee	–	Forest fragmentation increased the relative abundance of honeybees
[98]	Brazil	–	–	*Eulaema Athletica*	Oil palm; rubber tree		Fragment size and isolation did not affect genetic diversity
[110]	Costa Rica	12	0.9–16	Native bees	Farm	2	Fragment size did not affect bee abundance, diversity, and parasitism, and mortality rates in trap nests. Total bee abundance did not vary from edge to center. Species diversity was higher in the forest center
[13]	Ecuador	19	2.5–3500	Euglossine	Farm	0.3–17	Fragments area and isolation did not affect bee abundance, richness, or evenness
[80]	Brazil	30	15–25	Native bees	Mixed	–	Open areas had higher bee richness and diversity than forest patches
[106]	Australia	14	> 5, < 20	Native bees	–	–	Large forest fragments had higher taxonomic diversity of bees visiting flowers of trees than small fragments. Small fragments had higher mean body sizes than those in larger fragments. The abundance of stingless bees decreased in small fragments compared to large fragments
[118]	Japan	13	1.3–10	Native bees	Farm	–	Small patches can have the same potential in maintaining as large patches. Bee richness quickly increased at the small range of the area (< 3 ha)
[65]	USA	14	5–164	Solitary bees	Mixed	0.6–19	Forest patch size did not affect bee community structure or individual family occupancy
[76]	USA	–	–	*Bombus vosnesenskii*; *Bombus bifarius*	Forest	–	Forests did not act as barriers to the fine-scale movement for either species

Table 3 (continued)

References	Country	NP	Area	Pollinator	Matrix	Isolation	Key results
[44]	Norway	24	0.11–72	Bumblebee	Farm	0–428	Patch isolation negatively affected bumblebee abundance Forest fragmentation reduced the abundance of forest specialists while increasing the abundance of open-habitat species
[66]	Norway	24	–	Native bees	Farm	–	Patch complexity negatively affected the total number of pollinators

Table 4 Summary of the results of studies investigating amount, distance-dependent, and structural effects of forest patches on bees

	Country (%)	Distance/area (%)	Species (%)	Matrix (%)	Results (%)
Distance-dependent effects ($n = 36$)	Brazil (22)	< 2 km (83.3)	Native bee (63.8)	Coffee (27.7)	Negative (77.7)
	Other (78)	> 2 km (16.7)	Honeybee (36.1)	Other (72.3)	Positive (13.5)
Amount effects ($n = 33$)	Brazil (27.7)	< 2 km (75.7)	Native bee (85)	Soybean (12)	Negative (21)
	Other (72.3)	2 km (29.3)	Honeybee (15)	Other (88)	Positive (66.6)
Structural effects ($n = 31$)	Brazil (29)	Area < 100 ha (36)	Native bee (84)	Farm (58)	Negative (17)
	Other (71)	Area > 100 ha (64)	Honeybee (16)	Other (42)	Positive (47)

species were native bees and less attention was paid to honey bees in these studies. Both coffee and soybean crops have received more attention than other products. In the results column, the effects of amount, distance-dependent, and structural effects of forest patches on bee diversity are presented. For the distance-dependent effects of forest patches, negative means that the diversity of bees decreases with increasing distance from the forest. For the effects of the amount of forest cover, positive means that the presence of more forest cover has increased the diversity of bees. For the structural effects of patches, positive means that larger patches support a higher diversity of bees.

Discussion

Our data on the distance-dependent effects of forest patches showed that the bees' population and consequently pollination decreases with increasing distance from forest patches in agricultural farms. This result was confirmed by 77% of the studies presented in Table 1. However, 13.5% of these studies disagreed with this result, and 9% of the studies found no relationship between distance from forest patches and bees. The first question that arises in this regard is: at what distance from the forest patches a significant reduction of bees occurs? Various studies have examined different distances ranging from zero to 30 km of forest patches with an average of 1900 m. Although these studies do not specify at what distance from forest patches, for example, the bee population decreases by 50%, some studies claim that this decrease is exponential [55, 69, 75, 94]. For example, in a review study, Ricketts et al. [94] showed that with increasing distance from forest patches, the visiting rate and the abundance of pollinators decreased exponentially.

Nearly, 79% of our studies that have found a significant decrease in bees by increasing distances from forest patches have examined distances of less than 2 km. Therefore, it seems that at distances of more than 2 km from the forest patches we should not expect a significant presence of bees. For large-bodied bees, such as honeybees that can fly several kilometers, Chacoff and Aizen [25] found that honeybees decreased at distances greater than 500 m from the forest edge. Buchori et al. [22] also showed that pollinators were significantly lower on farms near (< 200) to natural habitats compared to those located far (> 1000). Another question is whether the size of forest patches affects the decreasing rate of bees with increasing distance from the patches. In other words, is there a difference between the distance-dependent effects of large and small patches? We mentioned earlier that the area of forest patches in the studies varies from 0.3 hectares to 65,000 hectares, with an average of 3100 hectares. None of these studies reported that with a distance of large patches, for example, 65,000 hectares [108], the rate of bee reduction is different from small patches. Therefore, it seems that even in the case of large patches, the population of bees at distances of more than 2 km significantly decreases.

One possible reason is that bees are unable to fly long distances. In a review, Zurbuchen et al. [132] examined the maximum foraging distances of bees. They found that the average maximum foraging distance for solitary bees was 1220, bumblebees 14,670, stingless bees 1520, and honeybees were about 6313 m. Therefore, as mentioned earlier, regardless of the size of forest patches, the type of species, and the matrix around the patches, the bees' population decreases significantly at distances more than 2 km. Another reason is that bees are the central place forger. Many animals, including bees, return to a central location after collecting food. Factors such as time, energy, and risk associated with the predator when transporting food to the nest also affect the location of the nests [84]. Central foragers build their nest in a place so that they save maximum energy and apply minimal effort to find the required resources. According to this theory, there is a maximum distance for the central place foragers that they do not go beyond this distance for foraging. Therefore, near the nest patches, all high-quality patches are visited, but at distances away from the nests, only the best patches are used [83].

Our data on the effects of forest cover on bees in agricultural landscapes showed that the presence of forest cover around the sampling sites has a positive effect on the presence of bees. This result was confirmed by 67% of the studies presented in Table 2. In these studies, the buffer around the sampling sites varied from 25 m to 15 km with an average of 1350 m. In other words, they measured the amount of forest cover in circles with an area of 0.19–70,650 hectares with an average of 572 hectares and examined its effects on bee populations. The question that arises here is in which radius of the sampling sites the highest correlation is seen between forest cover and bee population. Approximately, 76% of the studies that found the presence of forest cover positively affects the presence of bees; the maximum radius was less than 2 km. Therefore, it seems that by creating new forest cover in a radius of 2 km around the target sites, we can significantly increase the bee population. Wayo et al. [125] also showed that forest cover has a strong positive effect on stingless bee richness and abundance in a radius less than 2 km.

Some studies have provided the most important radius in their results. For example, Taki et al. [117] identified that only at the buffer of 750 m, forest cover had a positive effect on the and bee abundance and richness. At buffers from 200 to 1200, Brosi et al. [19] found that forest covers positively affected *Meliponine* richness. At the 1500-m scale, Taki et al. [119] also found a positive effect of forest cover on the abundance of *A. cerana*. Storck-Tonon and Peres [113] identified a radius of 250 m for positive effects of forest cover on bee richness. Rocha-Santos et al. [96] found that reproductive attributes of trees vanished quickly from forest remnants at a threshold at 25–30% of forest cover in the landscape. The sociality and generality of the bees can also affect the response that they give to the surrounding landscape. For example, Silva et al. [102] found that social bees responded to landscape characteristics at narrow scales (250 m), and solitary bees responded to broader scales (2000 m). Ferreira et al. [38] also found that specialist bees were more abundant in landscapes with more than 30% forest cover. With declining habitat, generalist species will appear more due to a lack of food resources. In landscapes where forest cover is less than 15%, pollinator populations may become extinct locally in small patches [38].

Our data also show that larger forest patches maintain a larger population of bees than smaller ones. Of the 23 articles that surveyed bee populations in forest patches, 11 (47%) found that larger patches had a greater potential than small ones to maintain a bee population. Some studies have shown the opposite (17%) and three articles claimed that the capacity of large and small patches was equal in maintaining bees, and 23% of studies found no significant relationship between patches size and bees. The area of forest patches in studies claiming that larger patches have a higher diversity and abundance of bees varies from 0.07 to 484 hectares, with an average of 125 hectares. These studies did not specify how much habitat was sufficient to maintain a viable population of bees and only compared patches that differed in size. For example, in a comparison between 14 patches having an area between 0.07 and 24 hectares, Calvillo et al. [23] found that the species diversity and richness in a 24-hectare patch was greater than the smaller ones. However, in a study comparing nine patches with areas between 2 and 18 hectares, Aguiar and Gaglianone [1] found that the smallest forest fragment had the highest abundance of bees. Therefore, no conclusion can be drawn about the size of the new patches needed to increase the bee population.

In addition to the size of the patches, it is necessary to determine the number and fragmentation pattern of new patches in a landscape. For example, Mitchell et al. [75] showed that the maximum levels of pollination occurred at the moderate habitat amounts fragmentation levels. Maurer et al. [70] found that forest fragmentation negatively affected bumblebees at low habitat amounts. At high habitat amounts, they found positive effects. In landscapes with low fragmentation, they also reported increased bee foraging activity. They found that fragmentation effects were strongly dependent on habitat amount in the landscapes.

Conclusion

Generally, our data showed that (1) by increasing the distance from forest patches, regardless of the type of species, the type of agricultural product around the patches, the size and number of patches, the bees' diversity and abundance decrease, (2) the presence of forest cover around the agricultural fields in most cases increases the population of bees in the fields, and (3) no conclusion can be drawn about the effects of forest patches size, shape, and number on the bee population. To determine how to increase pollination service in agricultural landscapes by creating new forest patches, two simulation studies have been performed recently. Based on the Lonsdorf model [67], Rahimi et al. [91] showed that maximum crop pollination occurred in the landscapes that had the highest forest fragmentation, meaning that new forest patches should be small and scattered in the landscape. In a similar study, they showed that if the capacity of small forest patches in supplying nests for bees is high, new small patches should be created sparsely around the fields. However, if the capacity of forest patches is low, the suggestion is to create large patches in smaller numbers around the farms [89]. Using artificial nests for attracting bees can also increase the capacity of small forest patches in supplying pollination [90]. In the present study, we sought experimental confirmations for the results of the simulation studies, but none of the studies we examined provided a clear answer to the question of how pollination could be increased by creating new forest patches. Therefore, future experimental studies need to seek answers to the following questions: (1) at what distance from the forest patches the bee population reaches 50% of its original population? (2) What percentage of the forest cover around farms guarantees an efficient population of bees for increasing pollination? Answering these questions can help landscape managers to estimate the optimal spatial pattern for new forest patches for increasing pollination.

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