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Exploring the effect of landscape composition and agroecological practices on wild bees in horticultural farms

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Abstract

How farms and the surrounding landscape are managed locally substantially affects biodiversity, with consequent impacts on the supply of certain ecosystem services, such as pollination. Wild bees provide pollination services for small-scale horticultural farming, and are key to determining and improving farm production, as well as maintaining ecosystem-level diversity. Here, we investigated how landscape composition and agroecological practices affect wild bee community in small-scale horticultural farms. The study was conducted at 16 horticultural farms in the northern part of Madrid. The pan-trapping method was used to collect wild bees during the flowering period of horticultural plants. We interviewed farmers to identify which agroecological practices were primarily adopted to attain a resilient ecosystem. The most common practices adopted were weed control methods, natural fertilizer usage, pest control, and crop diversification. In total, 109 wild bee species were identified, and included individuals from all six bee families present on the Iberian Peninsula. One genus (*Lasioglossum*) was highly abundant, accounting for 68% of individuals, and is a known ground nester. Areas of sparse vegetation and bare soil and forested areas primarily enhanced the richness of bee species. On the other hand, abundance of wild bees is enhanced by pasture and forest areas. The presence of these habitats in areas surrounding farms might represent the potential nesting sites with important resources for wild bees. Small-scale horticulture production promotes landscape diversity, which strongly promotes the potential of different ecosystem services, including pollination and wild bees. Thus, implementing agroecological practices could transcend farms, and individual fields, to the landscape level, providing long-term sustainability of ecosystems.

Keywords: Agroecosystem; Ecosystem services; Small scale farming; Horticulture; Agroecological transition; Wild bees

Introduction

The concept of agroecology began to (re)emerge as an alternative to the globalized and industrialized agrifood

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system (Gliessman et al., 2007; Méndez, Bacon, & Cohen, 2013). Agroecology seeks holistic and long-term solutions that empower producers and communities by applying ecological knowledge and processes in the design of food production systems. Although there is no unified definition of agroecology, it is generally understood as a science, a practice, and a political proposal related to rural socio-ecologically sustainable development (Altieri and Nicholls, 2012; Wezel et al., 2009).

Agroecological management implies the application of principles and ecological processes to the design of farming systems (Gliessman et al., 2007). It encompasses many practices, including crop diversification, cover crops, integrating semi-natural landscape elements, and minimum tillage (Hatt et al., 2016; Wezel et al., 2014). These practices focus on nature-based solutions for managing on-farm agrobiodiversity to attain resilient and sustainable agroecosystems, while reducing anthropogenic inputs as much as possible (Duru, Therond, & Fares, 2015). This (re)design of the system requires multiple levels of organization in agroecosystems, with changes at both the farm and landscape scale (Boeraeve, Dendoncker, Cornélis, Degrune, & Dufrêne, 2020; Hatt et al., 2016).

Agroecosystems depend on multiple regulating ecosystem services (ES), such as pollination, to supply certain provisioning services (such as food) (Zhang, Ricketts, Kremen, Carney, & Swinton, 2007). Thus, agroecology looks for agricultural practices that enhance regulating services (e.g. pollination), to supply other services over the long-term (Bommarco, Kleijn, & Potts, 2013; Wezel et al., 2014). Pollination is an ES provided by insects that contribute to the productivity of >75% of the world's crop species (Klein et al., 2007); consequently, it is an essential ES in the agroecological context. Insect pollinators are a key element for sustaining biodiversity and contributing to the functioning of most terrestrial ecosystems (Aizen, Garibaldi, Cunningham, & Klein, 2008). Bees (Hymenoptera: Apiformes) are the most important pollinator group in most ecosystems worldwide (Potts et al., 2010). Land-use changes, leading to landscape fragmentation and loss of landscape heterogeneity, are directly linked with the loss of biodiversity in farms (Klein et al., 2007). In turn, these changes contribute to declines in wild bee populations (Williams & Kremen, 2007). Separately and in interaction with landscape effects, local field management and agricultural practices strongly influence the wild bee community. Therefore, pollination is affected by both natural and anthropogenic systems (Batáry, Báldi, Kleijn, & Tscharntke, 2011; Kennedy et al., 2013).

In order to gain a comprehensive understanding of the intricate nature of agroecological systems, it is imperative to adopt methodological approaches that account for their complexity. Given that agroecosystems and their biodiversity are the result of intertwined ecological and social processes, it is advisable to examine them from both perspectives (Hatt et al., 2016) . The integration of local knowledge of farmers and researchers will improve the understanding of the system (e.g. wild bees) and the management of the agroecosystem (Duru et al., 2015). Indeed, this approach enables a deeper knowledge of the challenges that farmers face daily and promotes the development of sustainable agricultural practices that benefits both farmers and the environment (Palomo-Campesino, García-Llorente, & González, 2021).

Most studies have focused on the impacts of specific management practices on bees, rather than analyzing multiple practices in agroecological systems (Boeraeve et al., 2020; Palomo-Campesino, González, & García-Llorente, 2018). It is necessary to analyze realistic agroecological conditions using holistic approaches to elucidate how agroecosystems function, and to design practices adapted to local socio-ecological systems (Bommarco et al., 2013). Here, we aimed to quantify whether agroecological practices and landscape composition affect the wild bee community at the farm level. We implemented (1) biophysical sampling to identify wild bee species in horticultural production and (2) semi-structured interviews of farmers to identify agroecological practices in use. Through combining social and ecological approaches, our results are expected to reveal the complexity of social-ecological agroecosystems.

Materials and methods

Study location and farm selection

The study area was located in the northern part of the Madrid region, Spain, within an agricultural region called Lozoya-Somosierra (Fig. 1). Our study focuses on a mountainous area that has a granite landscape characterized by pastures and semi-natural habitats. The economy of the region is historically based on livestock production and forest resources (Aceituno-Mata, 2010). Agriculture has always been a marginal activity in this region, due to the climate and shallow soils; however, horticultural family gardens have always been maintained for self-supply (Acín Fanlo, 1996).

Within this region, we found 16 organic horticultural farmers willing to participate in the study. The selection criteria were that they produce organically and were situated at least 400 m apart from each other. We obtained contacts for farmers through visits to the area and by snowball sampling technique (Prell, Reed, Racin, & Hubacek, 2010). All farms were smaller than 1 ha (Table 1).

Data collection

Design of semi-structured interviews and data collection

Semi-structured and face to face interviews were conducted with all farmers (n = 16) during October 2019. The semi-structured interview was chosen as the central qualitative method for obtaining information on the agroecological practices (Newing, Eagle, Rajindra, & Watson, 2010). This method provides us an in-depth understanding on farmers

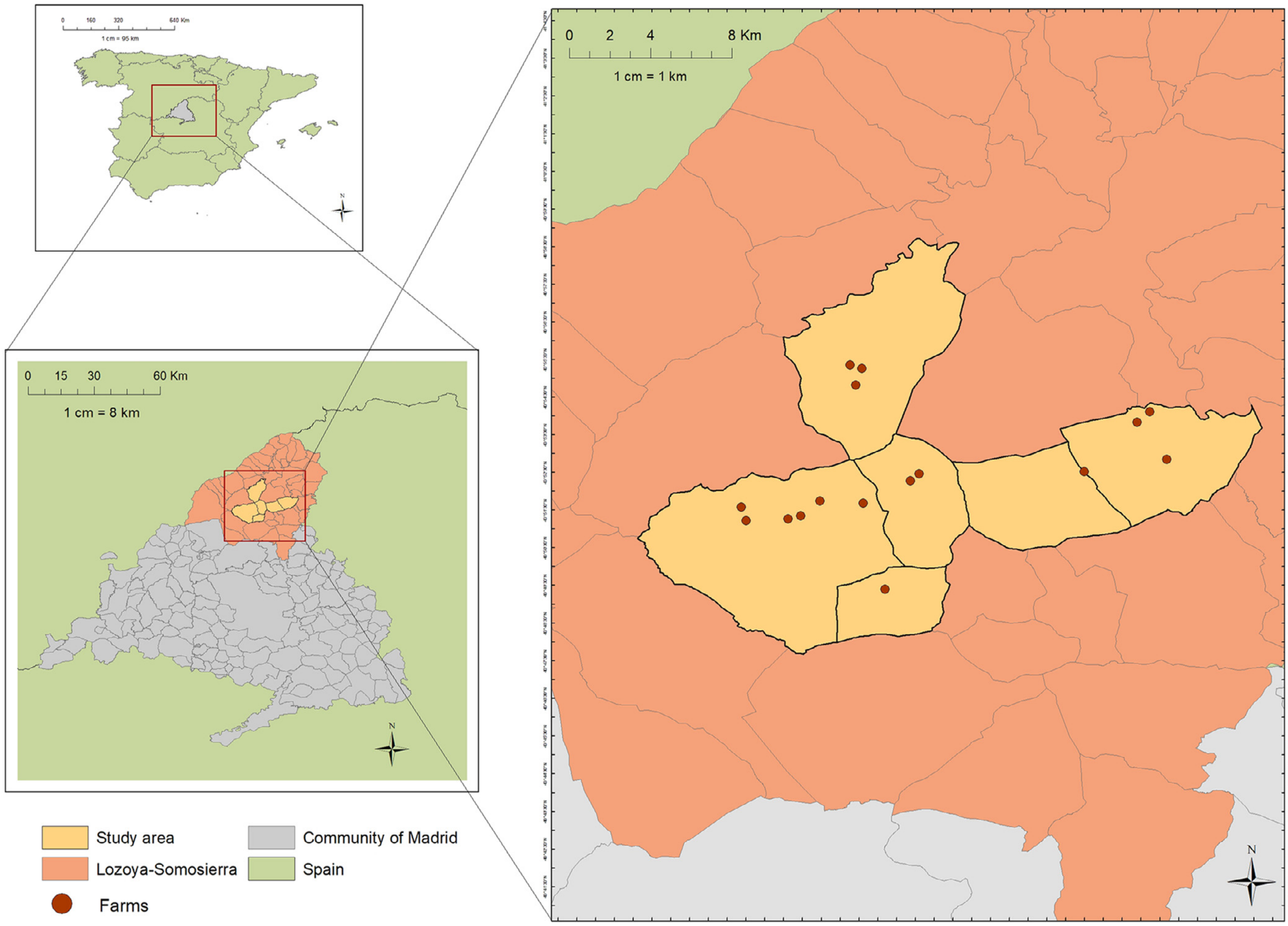

Fig. 1. Map of the study area and the selected farms (n = 16). The different municipalities in light orange are Navalafuente, Bustarviejo, Valdemanco, Garganta de los Montes, La Cabrera and El Berrueco.

situation and motivations behind the practices applied (Moon, Brewer, Januchowski-Hartley, Adams, & Blackman, 2016). The topics of the conversation were previously fixed by the researchers, and farmers were invited to talk without the order being predetermined. The first part obtained information about their relationship with the agricultural sector and general farm characteristics. The second part obtained information about their crops and the agroecological practices implemented, along with socioeconomic characteristics (Table 1). All farmers were informed

Table 1. Characterization of the farms included in the study (n = 16) including the location, people involved, purpose, project start and farm area (ha).

ID	Municipality	Ratio women/People involve	Purpose	Project start	Farm area (ha)
F1	Valdemanco	1/2	Professional	2015	0,14
F2	Valdemanco	0/1	Self-sustaining	2017	0,19
F3	El Berrueco	1/3	Self-sustaining	2015	0,13
F4	El Berrueco	2/6	Professional	2011	0,30
F5	El Berrueco	2/6	Professional	2017	0,25
F6	El Berrueco /La Cabrera	0/1	Self-sustaining	2002	0,33
F7	Garganta de los Montes	0/1	Self-sustaining	Before 2000	0,07
F8	Garganta de los Montes	1/2	Self-sustaining	Before 2000	0,05
F9	Garganta de los Montes	0/1	Self-sustaining	Before 2000	0,06
F10	Bustarviejo	1/4	Professional	2016	0,40
F11	Bustarviejo	1/4	Professional	2016	0,50
F12	Bustarviejo	0/1	Self-sustaining	2012	0,23

Table 2. List and description of agroecological practices included in the interview.

Index	Agricultural practices	Description
Biodiversity	Crop diversification	Cultivation of different crops at each farm
	Nest boxes for insects	Installation of nest boxes with sticks or wood facilitates nesting of wild bees
	Aromatic and melliferous plants	Cultivation of flowering plants, mainly mediterranean herbs, on the field within the cropping area or as buffer strips.
	Water collection	Collection of water for different purposes like irrigation
Production	Pest management	Techniques used for pest management to avoid pest damage
	Herb management	Techniques used for herb management control
	Crop association	Joint planting of different crops with the purpose of optimizing and promoting ecological processes as well as improving productivity
	Animal breeding	Use of animals or in the agrarian system (usually goats, sheep or hens)
Soil	Light ploughing	Reduction of tillage with different interests like herb control or facilitation of crop growth.
	Fallow land	Area of the farm which is sequentially uncultivated
	Fertilization	Substance input to supply nutrients to crops
	Cover crops	Plants planted between cultivation periods or between crop lines to avoid bare soil rather than with the purpose of being harvested
	Crop rotation	Cultivation of different crops sequentially on the same plot to improve soil health and pest management

beforehand about the objectives of the study, the anonymity of the interview information, and the research methods that were to be used. We provided them with a sheet containing all research information, and they signed a consent form.

Based on a review of the literature and previous field work in the area, we selected 13 common agroecological practices (Table 2) identified as practices that have a positive effect on the agroecosystem (Palomo-Campesino et al., 2018). We asked farmers which practices they implement, details on methods, and reasons and motivations for application, as well as their willingness to adopt practices they were not implementing. Since the practices applied differed slightly at each farm, we calculated an index of each practice based on application details (provided by each farmer in the questionnaire), following Palomo-Campesino et al. (2022). In brief, each practice was given a value based on its application, from 0 (not applied) to 1 (applied in the most sustainable way) (see Appendix A). Then, we multiplied this value with the time that the practice had been applied (0 to 1). We obtained a value for each agroecological practice and farm ranked from 0, when it was not applied, to 1, when it was applied sustainably for more than 10 years. To obtain an overview about the farms and practices, we grouped them in three indices: (1) soil management index (2) biodiversity conservation index, and (3) production index (Table 2).

Wild bee sampling

We used pan traps to survey bees in the 16 horticultural farms. Pan traps consisted of three plastic bowls painted with UV colors (yellow, blue, and white) filled with water and a few drops of soap to break the surface tension. These plates were placed at the height of the surrounding vegetation or crops. This is a common bee sampling method that suits different habitat types (Westphal et al., 2008).

Six sampling points were established on each farm. Sampling was carried out in June 2019 when most horticultural plants were at the flowering stage and pollination was needed. Pan traps were placed for 48 h and all the farms were sampled during the same week with sunny non-windy days. Then, all captured bees were stored in 70% ethanol until they could be prepared for identification (dried, fluffed, and pinned). Wild bees were identified to species level by an entomologist. We excluded counts of *Apis mellifera* from the analysis (Marini, Quaranta, Fontana, Biesmeijer, & Bommarco, 2012). Species richness and abundance were pooled from the six pan traps per farm and are the indicator variables used to study wild bee community.

Landscape composition

Landscape composition was mapped for each farm in a buffer of 400 m around the sampling sites. This radius was selected because the diversity of wild bees is influenced at small spatial scales within a 300 to 750 m radius (Kohler, Verhulst, Van Klink, & Kleijn, 2008). We used cartographic data from the National Plan for Aerial Orthophotography (PNOA) of Spain, which was processed for analysis using ArcMap 10.7.1 software.

The areas around farms were tessellated in detail to obtain land use and main vegetation cover (Fig. 2; Appendix B for a complete description of these areas). The area of each category was used to calculate the Shannon landscape index to assess landscape diversity as explanatory variable for the analysis. We also calculated the minimum distance to watered areas and to other horticultural farms using the Euclidean distance of vectors from the epicenter of farms to these areas using the “Euclidean distance” tool from ArcMap 10.7.

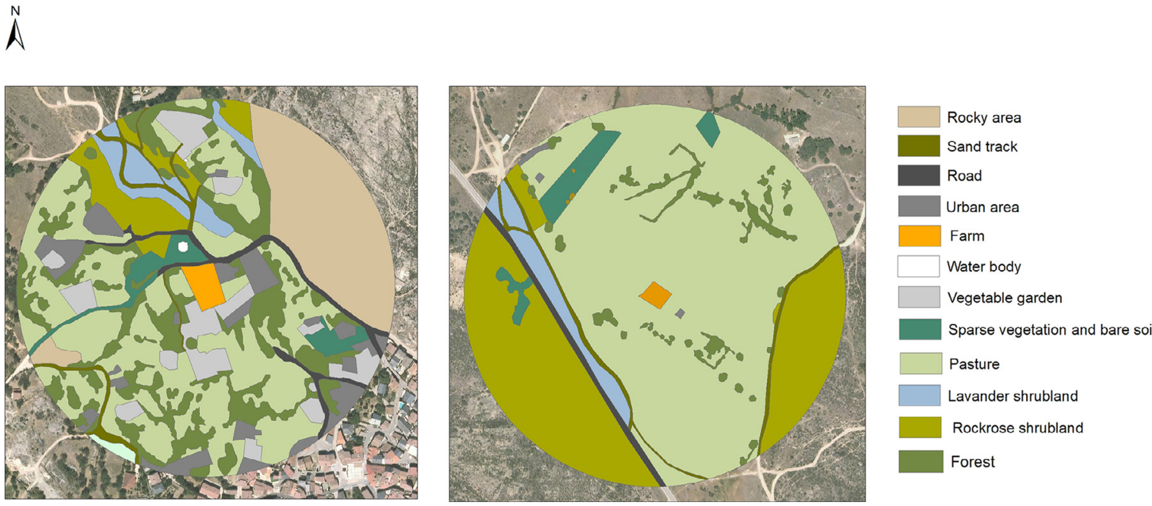

Fig. 2. Landscape units differentiated when tessellating the radius of 400 m around the different farms. These variables were used for a prior analysis and to calculate values of the Shannon landscape diversity index of the different farms (n = 16). Right map corresponds to the farm with the lowest Shannon diversity index (H`=1215) and left map corresponds to the farm with the highest Shannon diversity index (H`= 2134).

Data analysis

All data analyses were carried out using the R program (R Core Team, 2016). Data exploration was performed before the analysis (Zuur, Ieno, & Elphick, 2010). We grouped landscape variables that were ecologically related; different types of pasture were grouped as "pasture" and different types of forest stands were grouped as "forest" (Fig. 2). Two response variables (species richness and abundance of wild bees) and two groups of explanatory variables (landscape composition elements and management index) were generated (Table 3).

To explore the potential correlation between our variables, we performed a redundancy analysis (RDA) as a multivariate analysis to depict the correlation structure of the datasets. The R package used for multivariate analysis was "vegan" (Oksanen et al., 2018). We found collinearity between different variables and based on ecological reasoning we decided to exclude from the analysis the distance to watered areas and the distance to other farms (see correlation matrix, Appendix D). There was no significant correlation with any management index; thus, we only modelled the effect of the landscape variables on species richness and abundance through a generalized linear model (GLM) with

Table 3. Description of variables for the statistical analysis of landscape units (forest, pasture, sparse vegetation and bare soil areas), distance to watered areas and vegetable gardens, landscape heterogeneity, and agroecological practices grouped in three indexes.

Landscape Unit	Description
Forest	Areas covered mainly by pine, deciduous, oaks and riparian trees
Pasture	Areas covered with meadows (with or without livestock). It does not include wet meadows.
Sparse vegetation and bare soil areas	Areas where some patches of soil can be easily seen in the photographs due to sparse vegetation.
Distance to watered areas	Distance from farms to areas with water or with indications that the water was present (maybe not visible) like in the wet meadows or riparian trees.
Distance to vegetable gardens	Distances from farms to small plots cultivated for self-consumption of vegetables with similar characteristics to the ones that we have sample
Landscape heterogeneity	Shannon landscape index calculated with all tessellated areas found in the landscape composition analysis
Farm size	Total cultivated area
Biodiversity index	Including practices that enhance farm and landscape biodiversity: Crop diversification, nest boxes for insects, aromatic and melliferous plants, water collection
Production index	Including practices with influence on horticultural production, being them: pest management, herb management, crop association, animal breeding
Soil index	Including practices that have an effect (positive or negative) on soil, being them: Ploughing, fallow land, fertilization, cover crops and crop rotation

a Poisson error distribution. We also analyzed the potential effect of three agricultural practices (crop diversification, aromatic plants and light tillage) on our response variables using linear models.

Model selection was made using the second order Akaike Information Criterion (AICc), which is suitable for small sample sizes, as with our case (N = 16). The R package "AICcmodavg" was used (Mazerolle, 2017). Models with an AICc difference >2 from the most parsimonious model (the lowest value of AICc) were excluded (Burnham & Anderson, 1998).

Results

Agroecological practices applied by farmers

Farmers applied an average of 9 practices out of the 13 agroecological practices we asked about (Fig. 3). All practices were applied by at least one farmer. The practices applied by all farmers were the use of organic fertilizer (to provide sufficient nutrients to crops) and weed control (to minimize nutrient and space competition with crops). The practice of fertilization was highly diverse. All farmers used local manure, and 9 farmers (56%) used self-produced fertilizer (e.g., compost, nettle slurry, earthworms, humus). Weed control was implemented by hand, mulching, hoeing, or with a brush cutting machine. Following weed control and the use of organic fertilizer, most farmers performed crop diversification, pest control, and crop rotation. For pest control, farmers used a wide diversity of practices, mainly by hand, but also with their own methods (e.g., horsetail plants, potassium soap, tansy plants) (see Appendix A for details on practices).

The agroecological practices that were applied the least by farmers (<50% of farmers) were (in descending order of application): crop association, cover crops, fallow land, animal breeding, water collection and nest boxes for pollinators (Fig. 3). All farmers were aware of the positive impact of leaving the land to rest (fallow land) for a few months or seasons. However, the farmers claimed that they had very small farming areas and could not leave part of the land unproductive ("...but where can I have cover crops or fallow land If I barely have space for the crops I need for living?" (F4), "If I could have more land, I could think about it" (F11). Beehives and animal breeding were considered to require a higher workload and more space, which most farmers did not have on their properties. Green cover use was limited primarily because of the lack of knowledge about the technique. One farmer stated that seed mix could not be accessed in small quantities ("...I think the combination of seeds was not for this dry region, but also they said the minimum amount was for 1 ha..." (F10). Few farmers indicated their willingness to adopt new practices (Fig. 3). Nest-boxes for pollinators was the most mentioned practice, as it was considered to require low resources and limited extra work, followed by crop association.

Wild bee species diversity

Overall, 109 species (3618 individuals) belonging to 26 different genera were collected (see species list in Appendix C). We recorded Individuals of the six families present in the Iberian Peninsula. Only 10 individuals of the Melittidae family were recorded (all *Dasypoda argentata*), and just 48 individuals from the Megachilidae family. The most

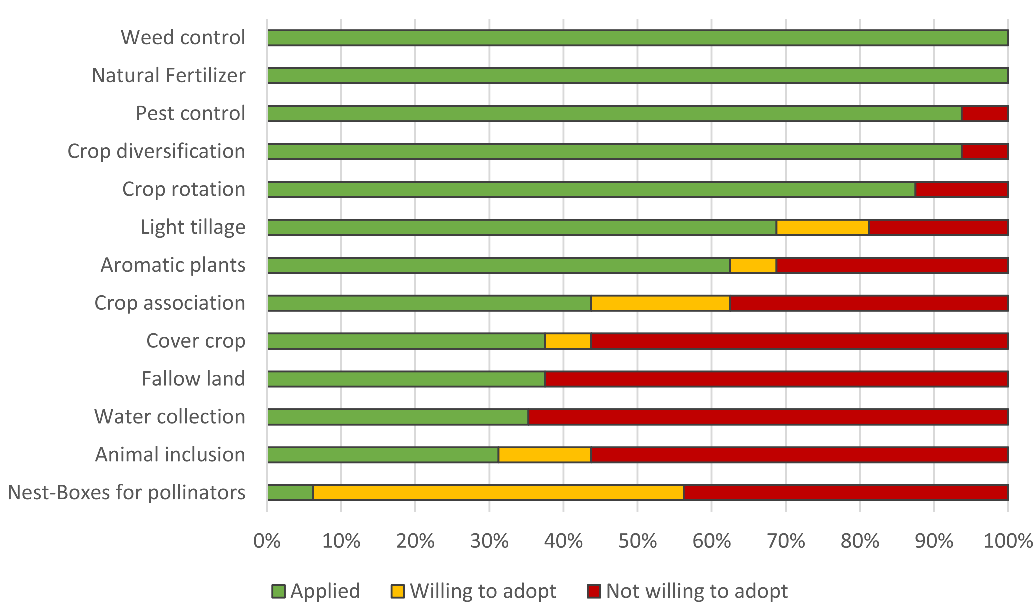

Fig. 3. Agroecological practices that farmers are applying (green), that they are willing to adopt (yellow) and that they are not willing to adopt (red).

Table 4. Six bee families present in the horticultural farms during sampling. Majority of bees are from the Halictidae family (89,25%) and the majority of bees collected are ground nesters (94,01%).

Family	% individuals (*n* = 3618)	Nesting type	% individuals (*n* = 3618)
Andrenidae	2,90%	Canes, dry wood, cavities, stems	3,99%
Apidae	4,48%	Soil	94,01%
Colletidae	1,77%	Parasites	1,00%
Halictidae	89,25%		
Megachilidae	1,33%		
Melittidae	0,28%		

predominant family was Halictidae, with 3229 individuals (i.e., 89.24% of all captured wild bees), followed by the Apidae family, with 162 individuals (4.47%). The most diverse genus was *Lasioglossum* (30 species), followed by *Halictus* (11 species) and *Andrena* (10 species). *Lasioglossum* was the most abundant genus as well, with 68% of all individuals (2467 individuals). Notably, 994 individuals were from the same species, *Lasioglossum albocinctum*.

Species richness was 34.3 species per farm on average (SD ± 6.63). The farms with the highest and lowest species richness had 47 and 24 species, respectively. There was more variability among individuals within the farms (SD ± 111.57), with 226 individuals per farm on average. Most genera belonged to bee species that nest in soil (95%), with just 4% (*Xylocopa, Ceratina, Megachile*, and *Anthidium*) nesting above ground (e.g., on dry wood, canes, or stems) and 1% were parasitoids (Ortiz-Sánchez et al. 2018á) (Table 4).

Effects of landscape and farming practices on wild bees

The RDA indicates significant linear relationship between some landscape elements and the wild bee community (F-value=2.92, p-value=0,04). The first axis of the RDA (62.84% of variance explained) revealed, based on positive scores, an association between species richness and two variables of the landscape: areas with scarce vegetation and bare ground and forest areas (see Appendix E). It also explains a relation between the abundance found in the different farms and the area of pasture around farms. The second axis of the RDA explains 14.11% of the variance. According to the analysis we found no correlation between species richness or abundance and the management index variables (production index, soil index and biodiversity index). Therefore, for the GLMs we only considered landscape composition variables.

Considering the response variables of wild bee species richness and abundance, we presented the coefficients of the two selected models with ΔAICc values <2 (Table 5). In the first model (Table 6), species richness was positively influenced by areas with sparse vegetation and bare ground (F = 12,497, p-value=0,003). The second-best model includes a combination of sparse vegetation and bare ground and forested areas (Respectively F = 8039, p-value=0,014; F = 2067, p-value=0,174). Both variables had positive coefficients, but only sparse vegetation and bare soil areas were statistically significant. However, forest area also has to be taken into account to explain species richness because ΔAICc values <2. Therefore, after GLMs, we can say that sparse vegetation and bare soil areas (model 1; Table 6), and its combination with forested areas (model 2; Table 6) presented favorable conditions for species richness of wild bees (Fig. 4). Regarding the models with the response variable of abundance, the most parsimonious model includes two explanatory variables. Wild bee abundance was positively influenced by pasture and forest areas (Respectively F = 6993, p-value=0,020; F = 3846, p-value=0,071) (Fig. 4). The most influential variable is pasture area, even though both explanatory variables (pasture and forest areas) explain better wild bee abundance (Table 6).

Table 5. GLMs for wild bee species richness, abundance and explanatory variables. The first four predictors (marked in bold) counted ΔAIC values lower than 2 and were, therefore, considered as influencing variables.

Response variable	Explanatory Variable	AICc	ΔAICc
Wild bee species richness	Sparse vegetation areas and bare ground	100,945	**0**
	Sparse vegetation areas and bare ground+ forest	102,618	**1,67**
	Sparse vegetation areas and bare ground + landscape heterogeneity	103,705	2,75
	Sparse vegetation areas and bare ground + pasture	103,852	–
Wild bee abundance	Pasture+ Forest	197,606	**0**
	Pasture	198,145	**0,53**

Table 6. Coefficients of the three different models selected, since their ΔAICc values were lower than 2, to explain the response variables wild bee species richness and wild bee abundance.

	Estimate	Standard error	Z value	P value
Response variable: species richness (Model 1)				
Sparse veg. & bare ground	0,095	0,030	3131	0,001
Response variable: species richness (Model 2)				
Sparse veg. & bare ground	0,078	0,033	2388	0,017
Forest	0,025	0,021	1182	0,237
Response variable: abundance (Model 3)				
Pasture	−0,0006	0,0002	−2658	0,019
Forest	−0,0005	0,0002	−1933	0,075

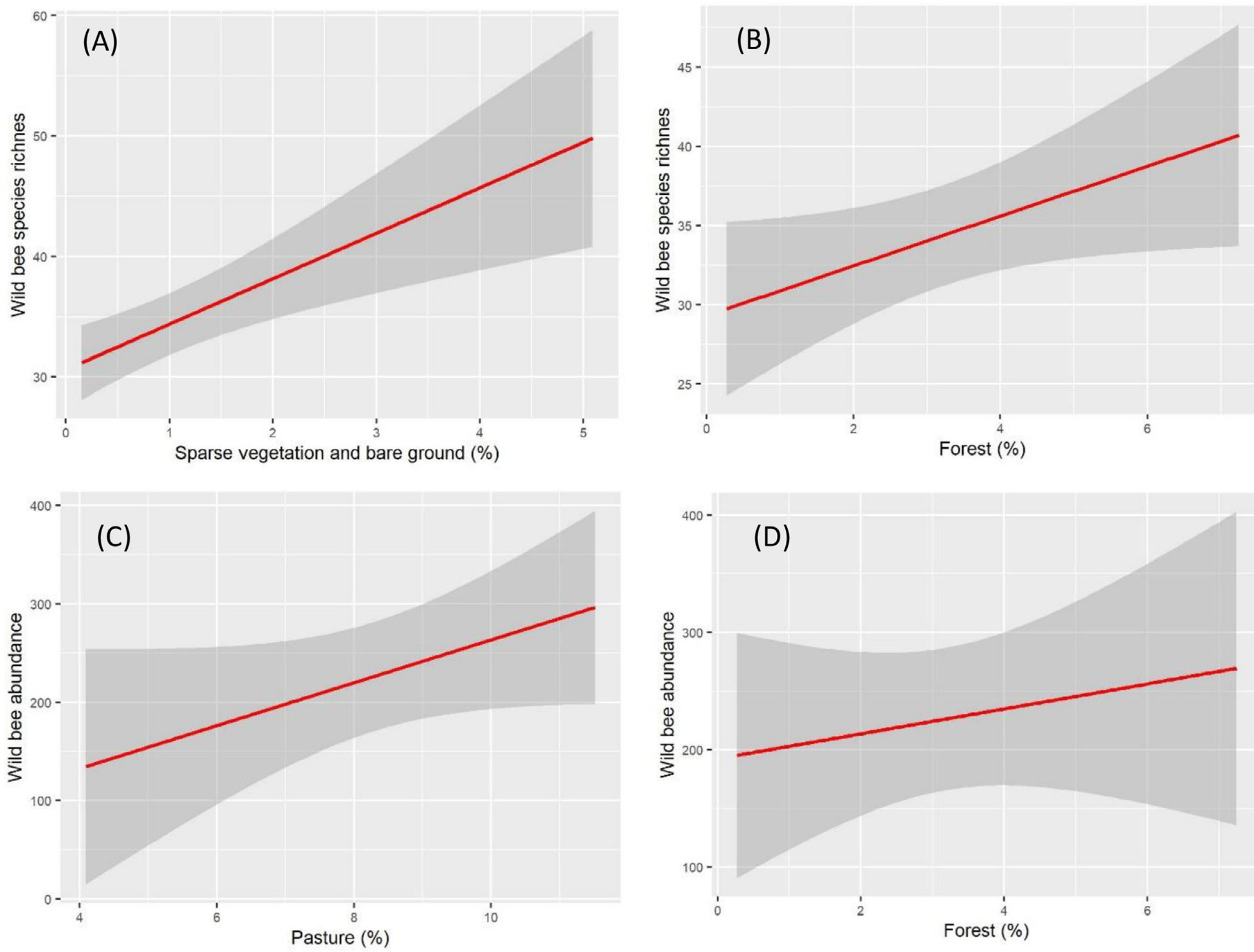

Fig. 4. The first two graphs show the effects of sparse vegetation and bare ground (A) and forest areas (B) on wild bee species richness in small horticultural farms. The second two graphs show the effect of pasture (C) and forest area (D) on abundance of wild bee species. Gray shading = 0.95 confidence intervals.

Regarding the linear models between species richness and concrete agroecological practices (crop diversification, aromatic plants and light tillage), we did not find any relation (Lm model, respectively: F = 0,039, p-value=0,84; F = 0,006, p-value=0,938; F = 0,074, p-value=0,788). Finally, in the linear models between species abundance and the same practices (crop diversification, aromatic plants and light tillage), we also did not find any relation (Lm model, respectively: F = 1.177, p-value=0,296; F = 0,460, p-value=0,508; F = 0,080, p-value=0,99).

Discussion

Agroecological sector in Madrid

Similar to other mountainous regions in the peninsula, a large part of the human population in our study area migrated to the city, and agriculture has since been maintained on a part-time basis. This phenomenon has allowed the survival of traditional farms oriented to self-consumption, without the need for mechanization (Aceituno-Mata, 2010). Yet, the number of organic and agroecological farms have experienced a positive trend in the last years (Simón-Rojo, Couceiro, del Valle, & Tojo, 2020). This is particularly important, because it is counteracting the trend of decreasing the number of agricultural farms (Soler & Fernández, 2015). Our data also supports this trend, as seven of our agroecological farms started their activity in the last decade. Of note, 40% of agroecological production in Madrid corresponds to horticultural production (del Valle, Jiménez, Morán, Clemente, & Medina, 2018), meaning that, within the agroecological sector, horticulture is particularly important.

Agroecological practices positively affect ecosystem services, providing an alternative to conventional practices (Duru et al., 2015; Palomo-Campesino et al., 2018; Wezel et al., 2014). Yet, to date, few of these practices have been integrated in the present-day agriculture. The adoption of some of these practices implies modification in the farming management or a system change (Wezel et al., 2014). Thus, modifications or changes to the system are likely blocking the adoption of these practices. Hill and MacRae (1995) delineated three stages to move towards a more sustainable agriculture: efficiency, substitution, and re-design. The practices that farmers primarily applied in our study region (weed control, natural fertilizer, pest control, and crop diversification) do not require high levels of system change, rather, changes at the field scale. These practices are considered at the substitution stage in the process of moving towards an agroecological transition (Duru et al., 2015; Wezel et al., 2014). In contrast, practices that were less frequently applied by farmers in our study region (e.g., cover crops, fallow land, and animal inclusion) require a certain level of change or redesign to the system. Recurrently mentioned reasons why farmers in our region did not apply some practices included their small farming areas and limited access to land. To apply these practices, farmers would need to redistribute land use or change their location, which means a higher level of system change. The limited space reserved for farming areas causes the problem of access to land, which represents a frequent barrier to the development of agroecological projects (del Valle et al., 2018; Soler & Fernández, 2015). This limited space for farming is the result of the social and landscape transformation that has occurred in the area (Aceituno-Mata, 2010).

The farmers in our study region performed a wide variety of agroecological practices. The use of these alternative practices shows that farmers are motivated beyond economic benefits, aiming to protect soil, biodiversity, and functionality of their agroecosystem. Previous studies of farmers concluded that agroecological practices are adopted based on lifestyle motivation and strong conservation values (Palomo-Campesino et al., 2021). In addition to environmental benefits, applying a wide variety of agricultural practices and reducing inputs increases the stability of the economic farm business over the long-term (Harkness et al., 2021).

Effects of farming practices and landscape composition on wild bee communities

There is growing scientific evidence that wild bees are influenced by both landscape characteristics and the local management of farms (Batáry et al., 2011; Concepción et al., 2012; Kennedy et al., 2013). However, most studies focus on binary categories, like organic vs. conventional management (Andersson, Rundlöf, & Henrik, 2012; Kennedy et al., 2013) or semi-natural habitat vs. cropland (Hevia et al., 2016; Winfree, Griswold, & Kremen, 2007) . Consequently, knowledge about the complexity of interactions remains limited. Therefore, the current study incorporated multiple agroecological practices to obtain a holistic view of farm management and diverse landscape elements. There was no evidence of agroecological practices impacting wild bees in our study, with our results showing that bees were mainly influenced by landscape composition. Our results showed that soil conservation practices (e.g., light tillage, fallow land, fertilization, cover crops, and crop rotation) had no clear effect on bees. However, previous studies suggested that fallow land, cover crops, and crop rotation are directly linked with the availability of flora resources on farms, and are considered beneficial practices for enhancing biodiversity (Andersson, Ekroos, Stjernman, Rundlöf, & Smith, 2014; Wilson et al., 2018). Furthermore, in addition to agroecological soil management, low disturbance is positively correlated with wild bee diversity (Palomo-Campesino et al. 2022). However, this may have different effects on different bee species, since the behavior and resources required by each of them can vary. For instance, Julier and Roulston (2009) reports that the nests of a native American wild bee species are more abundant in the fields compare to adjacent field margins.

We expected that biodiversity practices (e.g., crop diversification, aromatic and melliferous plants, and water collection) would positively impact wild bee communities, based on previous studies showing their positive effects (Kremen & Miles, 2012). These practices are directly related to floral resources for nectar and pollen, which are the basic resources required for the diet of wild bees. It is therefore interesting to question why we did not find effects on wild bees. Firstly, it is important to consider the possibility that agricultural practices applied by our farmers are not so intensive as to have a significant effect on wild bees. Secondly, agricultural practices might not have affected wild bee communities because of the size of the study farms (<1 ha), supporting Martin et al. (2020). They found that farming practices affect biodiversity differently depending on farm size and the heterogeneity of farmland (i.e., crop diversity).

Regarding landscape composition, our models showed that areas around horticultural farms are determinant for wild bee species richness and abundance. In particular, the combination of scarce vegetation and bare soil and forest areas for species richness, and pasture and forest areas to wild bee abundance (being scarce vegetation and pasture areas the most significant ones). These habitats might represent nesting areas, because ground nesters require bare soil, while cavity nesters require empty stems or cavities (Potts et al., 2005), which can be found in pasture and forest areas. While the specific nesting needs of ground-nesting species are still not known, they do not tend to create nests in areas with soil disturbance, such as crop fields (Williams et al., 2010). Therefore, areas surrounding farms with bare soil are important nesting habitats for bees, especially in our region where 89% of sampled bees were ground nesters. Other studies also showed that the availability of potential nesting cavities and bare ground strongly influenced local bee communities, so that it can be used as a proxy of wild bee communities (Potts et al., 2005; Sardiñas & Kremen, 2014). Open habitats, such as pasture areas, are characterized by abundant food resources by fast-growing of annual herbs, have been shown to favor wild bee communities (Penado et al., 2022). Other studies show that wild bees are also influenced by litter cover, sloping ground, and soil compaction (Burkle & Alarcón, 2011; Potts et al., 2005; Sardiñas & Kremen, 2014). While these parameters were not investigated here, they should be incorporated in future studies.

The benefits of implementing agroecological practices can transcend farms and individual fields to the habitat and landscape level. Thus, agricultural landscapes are a multifunctional matrix that should combine crop production and natural capital. Yet, most agricultural land is managed with a short-term vision and individual perspectives; therefore, collective management is essential to promote pollination and provide long-term sustainability of agricultural systems. Landowners must collaborate to realize landscape-level conservation and optimize the benefits generated by the provision of pollination services. These benefits are considered to exceed those achieved by individual efforts (Goldman, Thompson, & Daily, 2007; Stallman, 2011).

Conclusions

This study used semi-structured interviews and ecological data collection to demonstrate the variety of agroecological practices implemented by horticultural farmers and potential impacts on bee species. The wide diversity of agroecological practices implemented has been proven to enhance the sustainability and biodiversity of the agroecosystem. The most important factors enhancing wild bee communities in the agroecosystems around Madrid were surrounding areas with sparse vegetation and bare soil, as well as areas with forest vegetation and pasture areas. These areas might provide important resources for ground-nesting wild bees. In conclusion, our results provide empirical data on the importance of landscape management to improve the local biodiversity of horticultural farms to enhance production and long-term stability.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.baae.2023.05.003.

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