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Conserving wild bees for crop pollination: efficiency of bee hotels in Moroccan cherry orchards (*Prunus avium*)

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ORIGINAL RESEARCH ARTICLE

Conserving wild bees for crop pollination: efficiency of bee hotels in Moroccan cherry orchards (*Prunus avium*)

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ABSTRACT

Food production is highly dependent on pollination services provided by insects; 75% of the leading global food crops need animals for successful production. Pollinators, including managed and wild bees, are declining in many parts of the world. The loss of natural habitats providing nesting sites is considered as one of the main factors driving the decline of crop-visiting wild bees. The researchers had hypothesized that providing bee hotels in cherry orchards may be a useful strategy to support visitors of cherry flowers (*Prunus avium*). To test this hypothesis, observation was made on the attractiveness of bee hotels to wild bees in cherry orchards in Sefrou Province (Morocco). Bee hotels were installed at the border of two cherry orchards. Surrounding landscapes were described and pollinator communities were observed and sampled within bee hotels, cherry flowers, and also within the surrounding landscape. Bumblebees (*Bombus* spp.), Mason bees (*Osmia* spp.), sand bees (*Andrena* spp.), and sweat bees (*Lasioglossum* spp.) are the most abundant genera representing almost two-thirds of all wild bee visitors of cherry trees. Mason bees (*Osmia* spp.) are the most abundant bees nesting in bee hotels with almost three-quarters of all insects recorded. Bee hotels could therefore be used to sustain or even increase cavity-nesting bees visiting cherry orchards in Morocco.

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Landscape; *Osmia*; artificial nests; Megachilidae; *Prunus avium*

Introduction

Animals are required for the successful production of 75% of the world's most important food crops (Klein et al., 2007). Numerous studies showed that pollinators are globally declining in abundance and diversity due to anthropogenic disturbances, including habitat modification and fragmentation (Goulson et al., 2015; Potts et al., 2016). The global degradation of services provided by pollinators can therefore undermine the ability of agriculture to meet the demands of a growing and healthy human population (Chaplin-Kramer et al., 2014; Engelman, 2012; Potts et al., 2016; Tilman et al., 2001). As a solution, managed species like the domesticated honey bee, *Apis mellifera* L., can be used to provide reliable pollination but are sub-optimal or even not effective for many crops (Westerkamp, 1991), whereas the pollination services provided by wild pollinators are free, efficient, and complementary to the service provided by honey bees (Garibaldi et al. 2013; Holzschuh et al., 2012; Klein et al., 2007). Several studies showed that the pollination efficiency on a single visit basis for certain wild bee species was much higher compared with that of honey bees in certain crop systems (Garibaldi et al. 2013; Goulson et al., 2015; Zhang et al., 2015). Mitigation strategies have therefore to be developed to sustain efficient pollination services provided by wild pollinators.

Conservation plans can be developed to protect semi-natural areas surrounding crops and offer foraging resources (pollen and nectar) but also nesting resources (Holzschuh et al., 2012; Potts et al., 2005; Sutter et al., 2017). Many studies have shown that the productivity of crops such as coffee (Klein et al., 2003; Saturni et al., 2016), water melon (Kremen et al., 2002), or cherry (Chole et al., 2019; Holzschuh et al., 2012), is related to the presence of fragments of semi-natural habitats and of native vegetation in the surrounding landscape. Moreover, habitat enhancement can be developed in fields or orchards to provide additional floral and/or nesting resources. This study explored the use of artificial nesting resources developed for wild bees.

Wild bees are very diverse regarding the habitat in which they nest, the type of substrate they use, and the materials they require to build their nests. They can be divided into three main guilds on the basis of their nesting habits (O'Toole & Raw, 2004):

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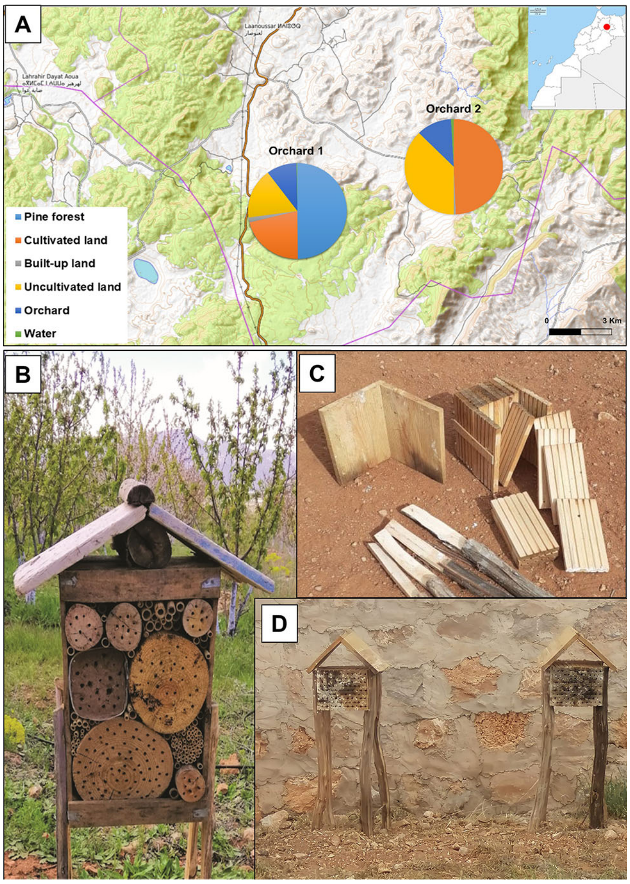

Figure 1. A, Location of the two cherry fields in the province of Sefrou, Morocco. Pies show the composition of the landscape at 1 Km radius around fields; B, Wooden log nest; C, Boards, roof, pillars used for the construction of wooden tray nest; D, Wooden tray nest.

cleptoparasitic bees, ground nesting bees, and cavity nesting bees. Cleptoparasitic bees, or cuckoo bees, do not build nests and are not able to collect pollen. They lay instead their eggs in nests of other bee species exploiting the pollen source stored by their host (Danforth et al., 2019; Lhomme & Hines, 2019). Ground nesting bees constitute the majority of bee species and dominate many open habitats worldwide (Michener, 2007; Michez et al., 2019). The cavity-nesting bees either nest in pre-existing holes or dig their own cavities in firm substrates (e.g., pithy plant stems or soft wood; Michener, 2007). Cavity-nesting bees like Megachilid bees are major pollinators for crops like cherry trees (Bosch et al., 2006; Eeraerts, 2020; Holzschuh et al., 2012). Cherry (*Prunus avium*) is one of the food crops showing a high dependency on insect pollination (Holzschuh et al., 2012).

Providing nesting support to cavity-nesting bees has been an efficient way to sustain cavity nesting pollinators (Bosch et al., 2006; Bosch & Kemp, 2005; Junqueira et al., 2012; Sampson et al., 2004; Yamamoto et al., 2014). Two types of artificial nests (so called "bee hotels") have been developed: 1) nests made of grooved wooden trays and 2) nests made of drilled wood logs.

The comparative efficiency of these bee hotels has rarely been investigated, in particular in African countries. This study aims to explore for the first time the use of bee hotels as a tool to sustain the visitors of cherry flowers in Morocco. The main objectives of this study are 1) to identify and compare the pollinators collected in bee hotels, cherry orchards, and in the surrounding landscape and 2) to compare wooden tray nests and wooden log nests installed near cherry orchards, in terms of costs for farmers and attractiveness to pollinators.

Materials and methods

Study site

In Morocco, the cherry orchards occupy an area of 3100 ha, with an annual production of 13,400 tons (Statistical directory of Morocco 2018, DSHCR). In the Sefrou province, where the study is conducted, cherry orchards spread over a total area of 393 ha. The researcher studied two cherry orchards (*Prunus avium*, variety Bigarreau Van). Orchard 1 (WGS: 33°36′56″N, 4°50′56″W, altitude 1459 m) was within an agricultural landscape surrounded by pine forest, other agricultural crops, and grassland. Orchard 2

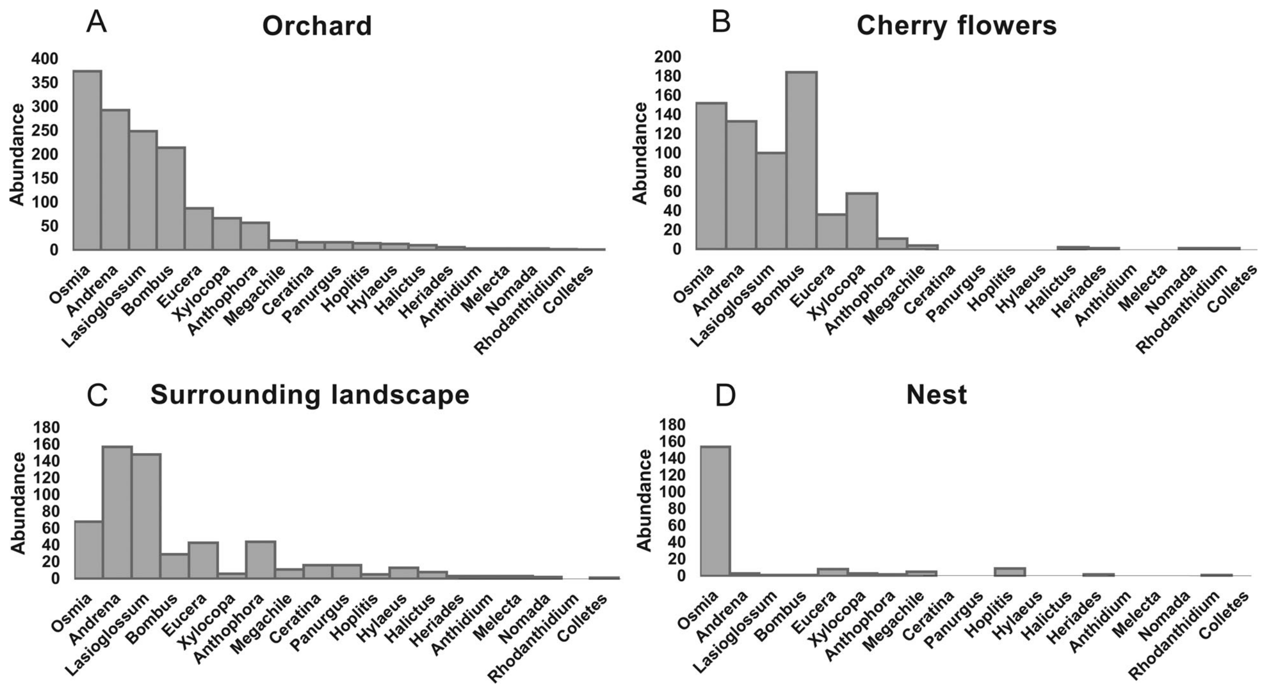

Figure 2. Distribution of abundance of wild bee genera in A, orchards, B, cherry flowers, C, surrounding landscape, D, nesting places.

(WGS: 33° 36′ 59 ″N – 4° 44′ 54″ W, altitude 1456 m) was surrounded by other orchards and agricultural land (Figure 1A).

The land use surrounding each cherry orchard was characterized in a radius of 1000 m using official topographical maps (1/25000) provided by the "Agence Nationale de la Conservation Foncière du Cadastre et de la Cartographie (ANCFCC)" of Morocco and completed by data from satellite images. Land use was calculated using Geographic Information Systems (QGIS version 3.12.2). Seven traditional land-use categories were used to characterize the landscape structure (Zou et al., 2017): orchard, pine forest, cultivated land, uncultivated land, water, road, and built-up land.

Nesting support

At each site, two types of bee hotels (one wooden log nest and two small wooden tray nest next to each other) were installed at the border of the orchards, separated by about 30 meters and oriented direction south-east facing the morning sun. The wooden log nests (Figure 1B) were made of various types of nesting materials known to be used by cavity-nesting bees, such as drilled logs and bamboo sticks. Different diameters of holes from 4 to 12 mm with depth varying from 10 to 15 cm were used. The wooden tray nests (Figure 1D) were made by a carpenter in Sefrou with cedar wood (Jennings & Parker, 1987), each of 20 wooden nesting boards with the same dimensions (length = 24 cm, width =12 cm) forming nesting holes of different diameters (4, 6 and 8 mm). The nesting holes were not drilled, but half pipes were grooved on both sides of the wooden boards, so that upon stacking of the boards a series of parallel tunnels was formed, then closed at one end by plaster. The two types of bee hotels were perched 1 m above ground level and protected against the rain with a small roof (Figure 1C). In 2019 only wooden log nests in each cherry orchard were used and in 2020 both types of bee hotels were used.

Wild bee monitoring

In February 2019 and 2020, before the flowering of cherry trees, the bee hotels were installed in the two orchards. A total of five days of sampling was used for covering all blooming periods of cherry. Sampling took place only during sunny days with a light wind and a temperature always exceeding 15 °C. During each sampling day, the collectors carried out four sampling rounds in each orchard at the same time (one collector per orchard) from 10 am to 5 pm (n = 20 sampling rounds per orchard). One sampling round consisted of 1) one sampling in each bee hotel (i.e., 10 min of visual observation and sampling with net of all insects entering the nests), 2) one sampling in the orchards (i.e., one observer walked slowly for 30 min along the trees of sweet cherry) and 3) one additional sampling in wild flowers surrounding the orchards (i.e., one person walked along a transect for 10 min). Only wild pollinators were sampled by net (honey bees were excluded). Moreover, three sets of three pan traps (volume of 500 ml, diameter of 145 mm, depth of 45 mm) colored in yellow, white, and blue UV-reflecting paint

Table 1. Comparison of fabrication, costs, and use of a wooden log nest and wooden trayy nest to help farmers to choose between both nests, the working hours are multiplied to 1.20 USD/hour (The minimum agricultural guaranteed wage of Morocco, SMAG).

Characteristics	Wood log nest	Wood tray nest
Material used	Logs	Grooved boards
Manufacture	Handy work	Artisan work
Reuse	No	Yes
Cleaning	No	Yes
Ease of fabrication	Simple	Complex
Lifespan	1 year	5 years
Total investment cost (5 years)	30 USD*	121.2 USD**
Maintenance cost (per year)	0	2.4 USD
Annual cost***	6 USD	26.6 USD

*Preparation and implementation costs (4 hours * 5 years) + drill rental (1 hour * 5 years).
**Nest purchase (109.29 USD) + implementation costs (2 hours * 5 years).
***Depreciation cost (total investment cost/5) + maintenance cost (per year).

(Rocol Top, Belgium) were also used to capture additional bee diversity in the landscape (Westphal et al., 2008). Two sets were placed between the lines within the cherry orchard and one set was placed outside the orchard. The pan traps were filled with water with a drop of detergent and exposed for 48 h. All specimens collected were pinned and identified to genus level following taxonomy presented in Lhomme et al. (2020) and identification keys of Michez et al. (2019).

Statistical analyses

All records were pooled per orchard (orchard1, orchard2) and per bee community (cherry blossoms, nests, and surrounding landscapes) to obtain the total richness (19 genera) and total abundance (1448 specimens) of wild bees. In order to compare the abundance and the richness between the two sites a Wilcoxon rank sum test was applied for each bee community. This non-parametric test was carried out as data were not normally distributed (Shapiro-Wilk test, $P < 0.05$). All analyses were performed using the free software R (version 3.6.3; R Core Team, 2020).

Results

Bee diversity

In total, 1448 specimens were collected (59%, N = 855) or observed (41%, N = 593) representing a total of 19 genera of wild bees. The five most abundant genera were *Osmia* Panzer (N = 374), *Andrena* Fabricius (N = 293), *Lasioglossum* Curtis (N = 249), *Bombus* Latreille (N = 214) and *Eucera* Scopoli (N = 87) (Figure 2A). Together, these five bee genera accounted for 84% of the records (Supplementary material, Table S1).

The visitors of cherry flowers (N = 683) were dominated by wild bees of genera *Bombus* (N = 184), *Osmia* (N = 152), *Andrena* (N = 133) and *Lasioglossum* (N = 100) (Figure 2B). These four genera represented 83% of the total visitors. The most abundant visitors collected in the fields surrounding the orchards (N = 576) were wild bees of genera *Andrena* (N = 157), *Lasioglossum* (N = 148), *Osmia* (N = 68), *Anthophora* Latreille (N = 44), and *Eucera* (N = 43) (Figure 2C). These five genera represented 80% of the total bees collected in the orchard surroundings. The insects visiting the artificial nests (N = 189) were mainly wild bees of genus *Osmia* (N = 154) (Figure 2D) representing 82% of the total assessed in the two types of nest.

Comparing Figure 2A and B shows clearly that *Bombus* and *Xylocopa* are attracted by cherry flowers. They may fly from a distance but they are very poorly represented in the surrounding area (Figure 2C). In contrast, *Andrena* and *Lasioglossum* are more abundant in the surrounding landscape (Figure 2C) than in orchard (Figure 2A) and on cherry flowers (Figure 2B). *Osmia* are the most abundant wild bees in the orchard (Figure 2A) and they are also the second most abundant flower visitors (Figure 2B) and they are clearly attracted by nesting material (Figure 2D).

Of the 19 wild bee genera sampled in both orchards, a total of nine bee genera (*Andrena, Anthophora, Bombus, Eucera, Heriades, Lasioglossum, Megachile, Osmia, Xylocopa*) were shared between cherry blossoms, nesting support, and surrounding landscape (Figure 3A). The genus *Rhodanthidium* was recorded only in nests and cherry blossoms. *Hoplitis* genus was present only in both nests and surrounding landscape, and two genera (*Nomada* and *Halictus*) were shared only between landscape and cherry blossoms. Six genera (*Anthidium, Ceratina, Colletes, Hylaeus, Melecta, Panurgus*) were only found in the surrounding landscape.

Bee hotels

The analysis result indicated that there is no significant difference between the wooden log nests and the wooden tray nests found in terms of genus richness (Wilcoxon test, $P = 0.29$) and abundance (Wilcoxon test, $p = 0.30$).

Variation between sites

The composition of the landscape surrounding the two study sites within a radius of 1000 m is different from one orchard to the other (Figure 1A). Orchard 1 is surrounded by 50% of low-density pine forest, 21% cultivated land, 17% uncultivated rocky land, and 10% Rosacea orchards. Orchard 2 is surrounded

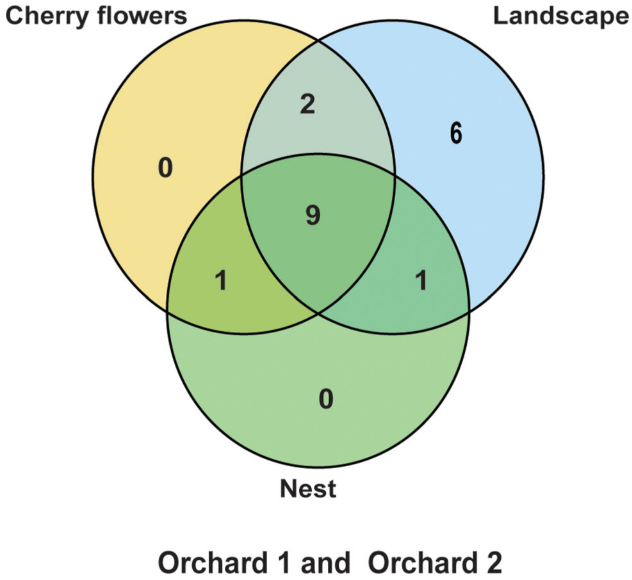

Figure 3. Venn diagrams showing the wild bees shared between the three communities presented in this study (wild bees visiting cherry flowers presented by the yellow circle, wild bees visiting the nest presented by the green circle and wild bees recorded in the surrounding landscape presented by the blue circle).

by 49% cultivated land, 38% uncultivated land, and 12% of Rosacea orchards.

The abundance of visitors of cherry blossom is much higher in orchard 1 compared to orchard 2 (Figure 4C) as well as for the abundance of visitors of bee hotels (Figure 4A). However, there are no significant differences between the two orchards in terms of the genus richness of these two communities (cherry flower visitors (Figure 4D) and bee hotel visitors (Figure 4B).

No significant difference between wild bee communities collected in the landscape of the two orchards was found either in terms of genus richness (Figure 4E) or in terms of visitor abundance (Figure 4F).

Discussion

Site variation

A limitation of the current study is that it was carried out in only two orchards. The researchers could therefore not accurately quantify the landscape impact on the abundance and diversity of pollinators, and their presence in bee hotels. They could however notice an important difference between both orchards showing different management techniques in the surrounding landscape. The quantification of the surrounding land composition of both orchards showed that 50% of the area around orchard 1 was covered by pine forest and 17% more with uncultivated land. Forests and forest edges often represent a refuge for pollinators; the abundance and diversity of pollinators are generally high in agricultural land adjacent to forests (Bailey et al., 2014; Joshi et al., 2016; Watson et al., 2011). Holzschuh et al. (2012) found that wild bee visitation in cherry orchards increased with the proportion of high-diversity bee habitats in the surrounding landscape; this could explain why they have a higher abundance of visitors of cherry blossom in orchard 1.

Orchard 2 surroundings are dominated by 49% of cultivated land and 38% of uncultivated land. The diversity of pollinators is known to decrease significantly with the increase in the proportion of cultivated land (Eeraerts et al., 2019; Zou et al., 2017). However, ground-nesting bees should benefit from uncultivated land, probably explaining the high abundance of such bees (*Andrena, Anthophora, Bombus, Eucera* and *Lasioglossum*) compared to cavity-nesting bees (e.g., *Osmia*) in orchard 2. The lack of significant difference in diversity between both landscape communities is perhaps also due to the fact that specimens were not identified to the species level.

Bee diversity within and around cherry orchards

The observations revealed that the main visitors of cherry blossoms in Sefrou (Morocco) are *Andrena, Bombus, Lasioglossum* and *Osmia*. These results are in line with several other studies showing that the most important cherry orchard pollinators belong to these genera even in countries with a different climate like Belgium (Eeraerts et al., 2017, 2020) or Germany (Holzschuh et al., 2012).

Moreover, cherry blossom orchards and their surrounding areas share the same 11 dominant genera of wild bees. This result is also in line with several studies showing that the composition of the surrounding landscape regulates insect communities in

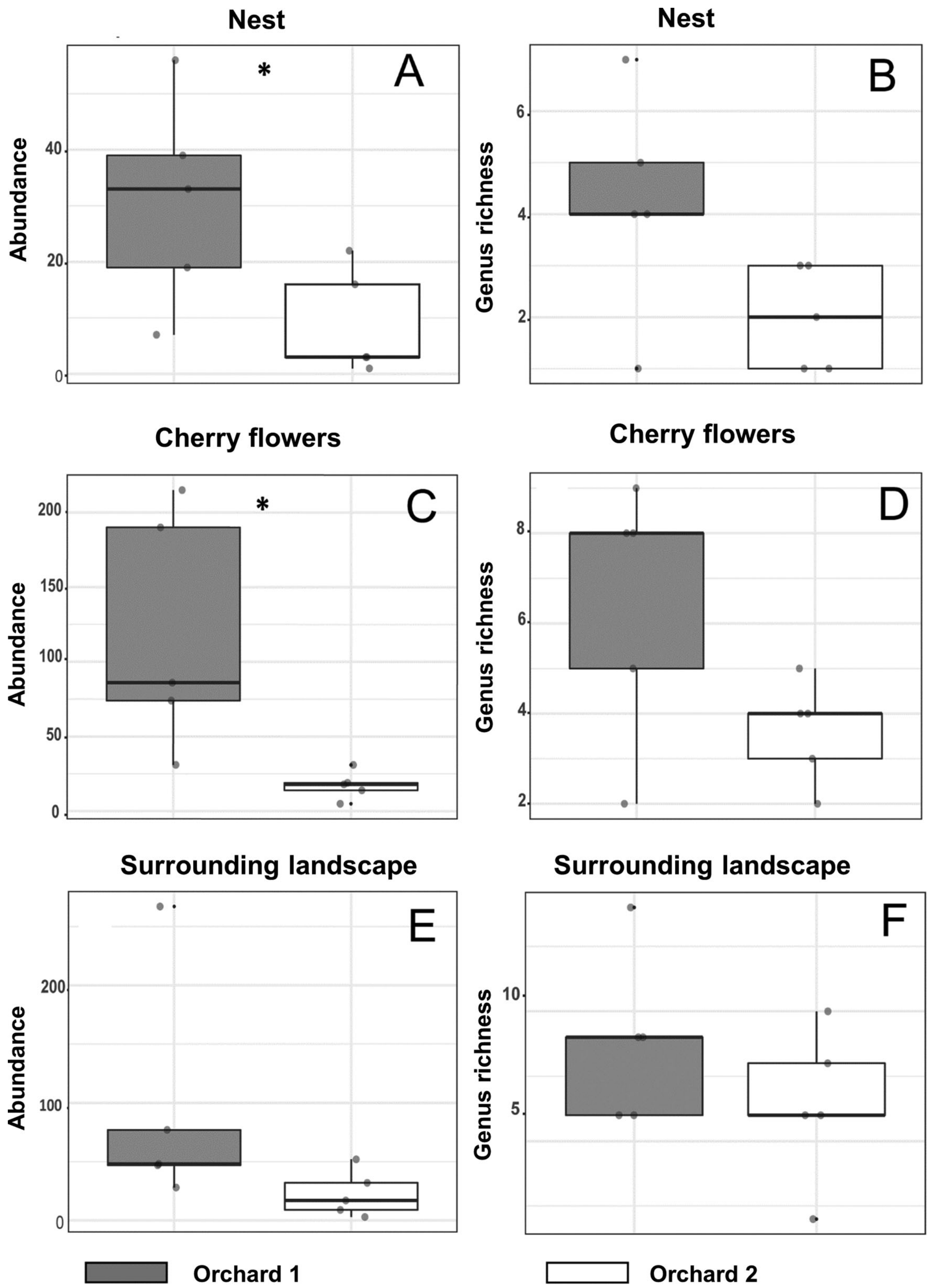

Figure 4. A, Wild bee abundance recorded on nests in orchard 1 and orchard 2; B, Genus richness of wild bee recorded on nests in orchard 1 and orchard 2; C, Wild bee abundance recorded on cherry flowers in orchard 1 and orchard 2; D, Genus richness of wild bee recorded on cherry flowers in orchard 1 and orchard 2; E, Wild bee abundance recorded in the landscape in orchard 1 and orchard 2; F, Genus richness of wild bee recorded in the landscape in orchard 1 and orchard 2, Box plots show the median and 25–75% percentiles. Whiskers show all data. Each data (circles) is represented. Asterisks indicate significant differences between box plots (*$p < 0.05$, **$p < 0.01$).

agricultural fields (Bartholomée et al., 2020; Eeraerts et al., 2017; Garibaldi et al. 2011; Greenleaf & Kremen, 2006; Holzschuh et al., 2012; Klein et al., 2003). In addition, Eeraerts et al. (2019) have shown that semi-natural habitats in the surrounding landscape of cherry orchards support pollinator species richness and wild pollinator abundance. However, *Bombus* and *Xylocopa* are important visitors of cherry flowers (Figure 2B) even if they are seldom in the surrounding area (Figure 2C) and absent from bee hotels (Figure 2D). Both genera are well known to be able to forage at long distances (Osborne et al., 2008; Zurbuchen et al., 2010) and they are likely flying from places out of the surveyed area.

Lastly, this present study shows that the nesting support installed at the edge of the orchards attracts the most important visitors of cherry blossoms (e.g., *Osmia*, see Figure 2A and D). These bees are known to be the most efficient pollinators of cherry trees (Bosch et al., 2006; Brittain et al., 2013; Eeraerts et al., 2020; Kuhn & Ambrose, 1984). Compared to the study of Eeraerts et al. (2017), where they studied the pollinator community composition in sweet cherry orchards without using bee hotels, this study found that the relative abundance of the genus *Osmia* recorded on the flowers has increased.

Efficiency of bee hotels

The two types of nests were equally attractive to cavity nesting bees and are both suggested to farmers (Table 1). Wooden log nests are easy to build, cheap (6 USD/year), but farmers must change them every year to avoid the propagation of parasites in the cavities, thus repeating the same effort each year (MacIvor & Packer, 2015). Wooden tray nests are much more costly to build (26.66 USD/year) and also more complex as they require a carpenter with adequate tools to carve the grooves of different diameters. However, this type of nest has a much longer lifespan (at least 5 years), is easy to clean, and can thus be reused year after year, with little effort. It is also an efficient way to remove parasitized cocoons (MacIvor & Packer, 2015).

Bee hotels are already used to manage and increase the number of wild bees to enhance pollination services (Bosch et al., 2006; Bosch & Kemp, 2005; Laliberté & Tylianakis, 2010; Sampson et al., 2004; Teper & Biliński, 2009; Yamamoto et al., 2014). Although there are no strict rules to design a bee hotel (Dicks et al., 2010), it is necessary to take into consideration several factors that play a role in the nesting success: material used [e.g., cedar (*Cedrus* spp.), pine (*Pinus* spp.), redwood (*Sequoia* spp.)] dimensions of the nest cavities (e.g., diameter: 4 to 12 mm, and length: 10 to 25 mm), orientation (facing morning sun), location (dry, elevated) and time of nest installation (early spring) (Bohart, 1972; Budrienė et al., 2004; Everaars et al., 2011; Gaston et al., 2005; O'Neill & O'Neill, 2013). Assessment of the main crop pollinators is also important to customize the bee hotels accordingly (hole diameters, material, etc ...) to ensure maximum nesting and pollination success (West & McCutcheon, 2009).

Pollination services provided by wild bees in cherry orchards cannot be compensated for only by honey bees (Holzschuh et al., 2012). It is therefore important to advise farmers to protect wild pollinators by preserving the natural habitats surrounding their orchards, minimizing the use of herbicides and pesticides, and providing nesting support for wild bees. The results show that providing nesting support can help to sustain pollinator communities in cherry orchards, especially when surrounding natural areas (e.g., forest) are absent. Additional studies are needed to test if bee hotels can mitigate bee diversity loss in agricultural landscapes even in Mediterranean mountain conditions.

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