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Do farmers care about pollinators? A cross-site comparison of farmers' perceptions, knowledge, and management practices for pollinator-dependent crops

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ABSTRACT

Pollinator conservation has become a key challenge to achieve sustainable agricultural landscapes and safeguard food supplies. Considering the potential negative effects of pollinator decline, international efforts have been developed to promote agri-environmental measures and pollinator-friendly management practices. However, little effort has been devoted to farmers' perceptions and knowledge about pollinators, or to farmers' role in enhancing pollination. We administered 376 face-to-face questionnaires in four areas of Spain with different dominant pollinator-dependent crops, to assess the factors behind farmers' perceptions, knowledge, and practices adopted to promote pollination. Overall, 92.7% of the respondents recognized that pollinator insects are necessary for crop production, and 73.4% perceived pollinator decline in their farms. We found that farmers had moderate knowledge about pollinators (6.1 ± 1.8, on a 1–10 scale). The most applied practices to promote pollinators were reducing insecticide spraying (53.2% of respondents), diversifying crops (42.8%), and increasing fallow fields (39.1%). Factors such as education, age, concern about the pollinator crisis, and professional dedication to agriculture strongly influenced farmers' knowledge and current application of pollinator-friendly practices. Implications of our results for the ongoing reform of the Common Agricultural Policy are discussed, highlighting the need to increase engagement and trust of farmers through communication and technical assistance.

KEYWORDS: cider-apple orchards; farmers' perception; horticultural crops; pear orchards; pollination; sunflower crops; sustainable agroecosystems

1. Introduction

Maintaining pollination services to assure present and future food production is currently a major challenge in the design of sustainable agroecosystems (Bartomeus and Dicks, 2019). Insect pollinators contribute to the productivity of more than 75% of important crop species (Klein et al., 2007; Kluser et al., 2010), representing 35% of the global crop production volume (IPBES, 2016). Globally, the agricultural production directly attributed to animal-mediated pollination has an estimated annual market value of US$ 235–577 billion worldwide (Archer et al., 2018; Gallai et al., 2009).

Furthermore, pollinators are inextricably linked to human well-being through the maintenance of wild plant reproduction and the safeguarding of ecosystem health and function (Kleijn et al., 2015; Potts et al., 2016). Pollinators underpin sustainable livelihoods that link ecosystems, cultural values, and customary governance systems across the world (Hill et al., 2019). Thus, conservation of pollinators has become crucial for advancing United Nations Sustainable Development Goals (Wood and DeClerck, 2015).

In recent years, several studies have reported important declines of different pollinator taxa (Biesmeijer et al., 2006; Potts et al., 2010; IPBES, 2016), including reductions in the abundance and diversity of wild bees in Europe, mainly attributed to anthropogenic drivers such as habitat fragmentation, agricultural intensification, and climate change (Biesmeijer et al., 2006; Potts et al., 2010). The intensification of agricultural landscapes in particular has reduced habitat diversity and availability (Tscharntke et al., 2005), which threatens wild bee populations that are strongly dependent on natural and semi-natural habitats (Saturni et al., 2016). Where “Red Lists” of Endangered Species are available, it has been estimated that more than 40% of wild bee species could be threatened (IPBES, 2016).

Critical voices from the scientific and political arenas have called for maintaining sustainable and healthy insect pollination (Gill et al., 2016). Global concern about the fate of pollinators has resulted in several continental, national, and regional programs intended to tackle pollinator declines (Potts et al., 2010). Considering the potential repercussions on agricultural productivity, the European Union has proposed a series of management practices to promote pollinator conservation and enhance pollination services (Scheper et al., 2013). These practices include support for diversified farming systems, maintenance of permanent grasslands, and protection of particular landscape features (Scheper et al., 2013; Dicks et al., 2016).

Understanding farmers’ perceptions of the role of pollinators and the practices adopted to promote them is essential and highly relevant to influence the way farmers manage their farms and participate in the implementation of agri-environmental measures (Herzon and Mikk, 2007; Meijer et al., 2015; Wilson and Hart, 2000). Sustainable agroecosystems should support biodiversity conservation and food production, and incorporation of farmers’ local knowledge and perceptions is essential to achieve both goals (Rawluk and Saunders, 2019). However, most research about pollination to date has focused on ecological studies of pollinators (e.g., Nicholson et al., 2017; Steffan-Dewenter et al., 2005) or on the their economic contributions to crop productivity and/or sustainability (e.g., Allsopp et al., 2008). Further research is needed to understand farmers’ perceptions and knowledge about the contributions provided by insect pollinators within agroecosystems (Smith and Sullivan, 2014). In a recent literature review, Rawluk and Saunders (2019) found an important gap in research on these topics, with only four papers exploring local knowledge on insect-provided pollination service. This represents an important limitation for the effective implementation of agri-environmental schemes to safeguard pollination services. As farmers are the ultimate managers of the agricultural landscape at the local and regional scale, it is essential to understand their perceptions to design innovative and sustainable solutions applied from a science–management–practice perspective.

In this research, we focus on several pollinator-dependent crops of high economic relevance in Spain, cider-apple orchards, mixed-fruit (mostly pear) orchards, sunflower crops, and horticultural crops (mostly tomato, pepper, cucumber, and melon), to tackle three specific goals: (1) assess farmers' perception and knowledge about the role of pollinators in their crops; (2) explore which sociocultural factors influence the perception and knowledge of farmers about pollinators and pollination service; and (3) analyze farmers' current adoption and future willingness to adopt agricultural practices that promote pollinator conservation and enhance pollination.

2. Methods

2.1 Study sites

We selected four study sites in Spain where the agricultural landscape is dominated by crops highly dependent on insect pollinators for seed or fruit production, and that are also relevant in economic terms (Fig. 1).

The Asturias study site (Fig. 1A) comprises six municipalities that represent the most important area for cider-apple (*Malus x domestica* Borkh) production in Spain, with around 10,000 ha devoted to this crop (INDUROT, 2010). Cider-apple orchards are frequently surrounded by natural hedgerows and embedded in a mosaic landscape that comprises multiple land cover types, such as livestock pastures, eucalyptus plantations, native forests, and heathlands. Cider-apple orchards are based on disease-resistant cultivars and low-input management, with low use of machinery and scarce use of chemicals (no fungicides, few pesticides, and herbicides restricted to areas under trees).

The study site of Las Vegas (Fig. 1B) is a rural district comprising 23 municipalities located in the south-eastern part of the Madrid region with an economy traditionally based on the farming sector and associated agri-food industries. The agricultural landscape is characterized by the presence of fluvial terraces with horticultural (mostly tomato, pepper, cucumber, and melon) and cereal crops, occupying nearly 53,000 ha. Olive groves and vineyards are also grown in lightly sloped soils with low levels of organic material (Pérez-Ramírez et al., 2019).

The study site of La Mancha (Fig. 1C) comprises nine municipalities in the Province of Cuenca. The agricultural landscape is dominated by non-irrigated cereals and oilseed sunflowers cultivated under an annual rotation regime, occupying nearly 31,600 ha. This area is one of the most important producers of sunflower oil in Spain. Sunflowers are farmed under an intensive regime that includes the use of herbicides and various types of fertilizers.

The Murcia study site (Fig. 1D) comprises the municipality of Jumilla, with a landscape composed of 64% of cultivated area, some residual holm oaks, and formations of Aleppo pine (*Pinus halepensis*) with Mediterranean scrublands. The dominant crops are vines, olives, almonds, pears, and peaches. Particularly, pear orchards occupy nearly 1,200 ha; Jumilla is the largest producer of the Ercolini cultivar both in Spain and in Europe, producing almost 22,000 tons annually (48% and 24% of national and European production respectively).

2.2 Data collection

A total of 376 direct face-to-face standardized questionnaires were conducted in the study areas (90 questionnaires in the cider-apple orchards of Asturias, 116 in horticultural crops of the Las Vegas district, 103 in the sunflower crops of La Mancha, and 67 in the mixed-fruit orchards of Jumilla), from January to September 2018. The sampled population was restricted to individuals over 18 years old whose activity was linked to the agricultural sector. Agricultural extension offices, municipalities, and public areas (e.g., public parks, snack bars, and town squares) were used to find farmers in each of the study sites. Snow-ball sampling technique (Bernard, 2005; Bryman, 2012) was then used to locate new farmers and people with farming-related jobs (e.g., agroindustry professionals, members of farmers' unions or cooperatives, and local development agents). Based on the sample size and the total number of registered farmers of each study area, the sampling errors at the 95% confidence level were estimated as ±9.0% in Asturias, ±9.5% in La Mancha, ±9.7% in Madrid, and ±10.0% in Murcia. More details about the sampled population are provided in Table 1.

The survey began with a brief introduction explaining the purpose of the study. Then, respondents were asked about their perceptions and knowledge of pollination services in their farms, following a questionnaire structured into four major sections: (1) knowledge about pollinators and their role in crop production (specifically, respondents were asked about the roles of beetles, wasps, honeybees, butterflies, flies, bumblebees, other wild bees, and ants); (2) perception of the conservation status of pollinators and the drivers of change currently affecting them; (3) main practices currently implemented in their fields, and willingness to adopt other management practices to promote pollinators, with specific questioning about their perception on the beneficial or harmful effect of the different practices; and (4) socio-cultural characteristics (i.e., place of residence, formal education, age, gender, and dedication). More details on the structure and the different questions that formed the questionnaire are provided in Appendix A. Two questionnaire models were used, with the question order changed to avoid any sequence effects (García-Llorente et al., 2012).

2.3 Data analysis

We performed frequency analyses on farmers' perception of: (a) the pollination dependency of their crops, (b) the importance of different pollinator taxa for crop pollination, (c) the status and trends of pollinators and current drivers of change, and (d) the beneficial and harmful effects of different agricultural management practices on pollinators. To analyze farmers' knowledge of pollinators and the role of pollinators in their crops, we built an "index of pollination knowledge" (IPK) by comparing the responses of farmers to four questions of the questionnaire with the answers to the same questions provided by experts in the field from each of the different study sites (see Appendix B). The IPK ranged from 0 to 10, with higher values indicating knowledge more concordant with the experts' criteria. ANOVA tests were performed to test the differences in farmers' pollination knowledge between the four study sites.

A stepwise multiple regression was performed to uncover socio-cultural factors that better explained farmers' knowledge (IPK) about the importance of pollinators for their crops. Five independent socio-cultural variables were used to build the model. The Akaike information criterion (AIC) was used to select the most parsimonious model.

Finally, we performed a redundancy analysis (RDA) to explore farmers' adoption of management practices to promote pollinators (dependent variables) and the socio-cultural factors influencing that adoption (explanatory variables). A Monte Carlo permutation test (1,000 permutations) was performed to determine the significance of explanatory variables in determining farmer’s adoption of pollinator-friendly practices. All analyses were performed with the XLSTAT software (Addinsoft, France).

3. Results

3.1 Farmers’ perception of the status and roles of pollinators in their crops

Overall, 92.7% of the respondents recognized that pollinator insects are necessary for food production, ranging from 88% in farmers of sunflower crops to 95% in farmers of mixed-fruit orchards. Farmers in the four study sites clearly identified honeybees as the main pollinators of their crops, followed by bumblebees and other wild bees (Fig. 2A). The role of bumblebees was particularly highlighted in the case of cider-apple and mixed-fruit orchards, whereas the role of other wild bees was highlighted in mixed-fruit orchards and horticultural crops. Other potential pollinators (e.g., flies, butterflies, beetles) were considered less relevant by respondents in the four study sites (Fig. 2A).

Overall, 73.4% of the respondents perceived that pollinators have declined in their farms, ranging from 58.2% of respondents in mixed-fruit orchards of Murcia, to 82.5% in sunflower crops of La Mancha. Farmers’ perceptions on the causes of this decline differed slightly among study sites (Fig. 2B), although most farmers consistently perceived the use of insecticides, climate change, and the loss of natural habitats as the most relevant drivers behind pollinators’ decline. In the case of cider-apple farmers, the roles of predators and agricultural practices were also highlighted. In addition, pests and diseases (e.g., *Varroa* mite, viruses, fungi) were considered to be important causes of pollinator decline by cider-apple and mixed-fruit farmers.

Finally, regarding farmers’ perceptions on the beneficial and harmful effects of different agricultural practices on pollinators, results were highly consistent among the four study areas (Fig. 3). Farmers consistently perceived as beneficial to pollinators the sowing of melliferous flora (97.15% of respondents), maintenance of wildflowers within fields (94.6%), conservation of natural or semi-natural field edges (85.2%), crop rotations (77.2%), and fallow fields (60%). In contrast, insecticide spraying (97.7%) and monocultures (90%) were considered to be the most harmful practices for pollinators, followed by the use of hybrid transgenic varieties (83%) (Fig. 3). Although not very important, the role of plowing seemed more controversial, with some farmers considering it harmful (31.0%) and others beneficial (17.1%).

3.2 Farmers' knowledge about pollinators and their role in crop production

Farmers' IPK (ranging from 0 to 10) showed a mean value of 6.11 (SD= 1.8) for the whole sample, which indicates a medium level of knowledge among respondents. However, significant differences were observed between sites (F = 25.836; d.f. = 3; P < 0.001; Fig. 4); farmers of cider-apple orchards in Asturias showed significantly lower IPK values (mean = 5.06; SD = 1.16), and farmers of mixed-fruit trees in Murcia showed higher values (mean = 7.20; SD = 1.39).

Regarding the factors influencing farmers' knowledge about pollination, the most parsimonious regression model showed that the IPK was positively related to the farmer's education level, concern about the pollinator crisis, and professional dedication to agriculture, whereas it was negatively related to age (F = 10.035; d.f. = 5; P < 0.001) (Table 2).

3.3 Farmers' current adoption and willingness to adopt management practices to promote pollinators

Overall, 75.5% of the respondents were currently adopting at least one management practice to promote pollinators. Specifically, the management practices most applied by farmers to promote pollinators in their fields were reducing insecticide spraying (53.2% of respondents), diversifying crops (42.8%), and increasing the number of fallow fields (39.1%).

RDA revealed associations between several socio-cultural characteristics of the farmers and the adoption of different measures to protect pollinators (Fig. 5). The first axis of the RDA (59.28% of the variance) showed that full-time dedication to farming and degree of concern about pollinators were related to implementing fallow fields, diversifying crops, and reducing plowing and hybrid seeds. The second axis of the RDA (28.19% of the variance) revealed that a high level of education was mainly associated with three practices to promote pollinators: maintaining wildflowers within fields, reducing spraying, and conserving crop edges.

Respondents associated with each crop type showed different patterns in current application, perception of effectiveness, and willingness to adopt management practices to promote pollinators. Cider-apple orchard farmers considered all the proposed practices to promote pollinators quite effective, but only three of these practices were highly applied in this study area (wildflowers within fields, reduced spraying, and conservation of crop edges). Further, cider-apple orchard farmers not currently applying pollinator-friendly practices showed high willingness to adopt many of the proposed management practices, except for the conservation of crop edges (Fig. 6A).

Farmers of horticultural crops in Las Vegas considered diversifying crops, reducing spraying, and installing floral plants within their fields to be the most effective practices for pollinators; reducing spraying, diversifying crops, and increasing the number of fallow fields were the most commonly currently applied practices. Further, respondents not currently applying pollinator-friendly practices in this study site only showed high willingness to increase the number of fallow fields and conserve crop edges in their fields (Fig. 6B).

Sunflower farmers considered the reduction of spraying and installing floral plants within their fields to be the most effective practices to favor pollinators; reducing spraying, diversifying their crops, and increasing the number of fallow fields were currently the most applied practices. The sunflower farmers showed a high willingness to adopt practices such as conserving crop edges, reducing the use of hybrid seeds, and increasing the number of fallow fields (Fig. 6C).

Farmers of mixed-fruit orchards in Murcia considered sowing floral plants and reducing spraying to be the most effective practices for pollinators; the reduction of plowing and the maintenance of wildflowers within fields were the most applied practices. Most respondents showed high willingness to adopt several other management practices, with the exception of increasing the installation of nest-boxes for bees (Fig. 6D).

4. Discussion

4.1 Farmers’ perception and knowledge of pollinators and their role in crops

Previous studies have indicated a widespread perception among farmers of pollinators' importance for their crops (Gaines-Day et al., 2017; Hanes et al., 2013; Park et al., 2018). Conversely, other studies have shown that farmers were not aware of the role of pollinators, even in the case of pollinator-dependent crops (Kasina et al., 2009; Munyuli, 2011). Lack of awareness seems particularly prevalent regarding the role of solitary wild bees, whose relevance is frequently underrated by farmers (Smith et al., 2017). Our results show that farmers associated with four different pollinator-dependent crops in Spain were able to identify the main pollinators of their crops, and most farmers, regardless of the study area, were well aware that pollinator insects are necessary for crop production.

Remarkably, we found greater appreciation for honeybees as valuable pollinators among all respondents, which is in line with previous scientific evidence that has recognized the honeybee as the single most important species for crop pollination (Geldmann et al., 2018; Klein et al., 2007). However, the important role of wild bees (Garibaldi et al., 2013), particularly bumblebees (Eeraerts et al., 2020; Garibaldi et al., 2013), in enhancing pollination is not always well perceived by farmers. We found that farmers of horticultural crops and mixed-fruit orchards perceived an important role of bumblebees and other wild bees, whereas farmers of sunflower crops and cider-apple orchards perceived this role as less relevant. In the case of cider-apple orchards, it is interesting to note that farmers also perceived bumblebees and honeybees as the main pollinators of their crops, whereas previous studies have shown low pollinating efficiency of honeybees in apple orchards (Blitzer et al., 2016; Miñarro and García, 2018; Vicens and Bosch, 2000). In general, farmers' knowledge about the real pollination efficiency of wild bees appears to be somewhat limited (Holzschuh et al., 2012).

Regarding pollinators' status and trends, our results show that farmers perceived a decline in the number of pollinators in their farms, which is in line with current scientific evidence (IPBES, 2016). Most farmers perceived insecticide use, climate change, and loss of natural habitats as the most relevant causes of pollinators' decline. Predators and pest diseases (e.g., *Varroa* mite, viruses, fungi; IPBES, 2016) were also pointed out as important causes of decline, but only in permanent orchards. These findings reveal fairly good knowledge among farmers of the major drivers of the pollinator crisis identified at the European level over the past decades (Archer et al., 2018; Sánchez-Bayo and Wyckhuys, 2019). These current trends are altering not only pollination service, but also other important services such as natural pest control and nutrient recycling (Aizen et al., 2009), which, in turn, may have negative effects on crop production (Zhang et al., 2007).

Regarding the socio-cultural factors that influence farmers' knowledge about pollinators and pollination, our results reveal that full dedication to agriculture and higher education level are associated with a higher degree of concern and better knowledge. Contrarily, farmer age was negatively related with pollination-knowledge, probably due to the lower education level of older farmers. Gender did not have a significant influence on pollination-knowledge, although our sample was largely skewed toward men. In general, the observed trends are consistent with previous studies in other intensive agroecosystems, which found that older farmers are less willing to change management practices, while more educated farmers are more aware and willing to adopt conservation schemes (Ahnström et al., 2009).

4.2 What are farmers doing and willing to do to promote pollinators?

To maintain adequate pollination service by wild bees, it is essential to provide foraging and nesting sites in the agricultural landscape (Schulp et al., 2014). Predominant agricultural practices (e.g., plowing and pesticide application) usually make intensive crops unsuitable permanent habitats for wild bees (Holzschuh et al., 2012). Focusing on the protection of pollinators and enhancing pollination, European agri-environmental schemes have promoted several pollinator-friendly practices (e.g., flowering hedgerows, fallow fields, conserving crop edges) (Kremen and Miles, 2012; M'Gonigle et al., 2015; Wood et al., 2015). Recent studies suggest that leaving land fallow is one of the most promising approaches for supporting and enhancing biodiversity in agro- ecosystems

(Robleño et al., 2018). Maintaining strips of natural or semi-natural elements (e.g., herbaceous plants, hedgerows or bushes) between adjacent fields has also been identified as a positive practice to enhance pollinator conservation in intensive agricultural landscapes.

However, our results show that current application of management practices to promote pollinators was still scarce in our study sites, and that not all pollinator-friendly practices were well accepted by farmers. In permanent orchards (e.g., cider-apple orchards and mixed-fruit orchards), we found that the agricultural practices most commonly applied were the maintenance of wildflowers within fields, reducing spraying, and conservation of crop edges. In contrast, in herbaceous crops (e.g., horticultural and sunflower crops), reducing spraying, diversifying crops, and increasing the number of fallow fields were currently the most applied practices. These different trends in implementing pollinator-friendly practices may respond to the distinct management requirements of each crop type (permanent vs. annual crops).

Despite the low current application, farmers showed relatively high willingness to adopt management practices to promote pollinators, but with differences among crop types. Our results show two major trends that correspond to the above-mentioned crop types. Farmers of permanent crops were much more willing to apply several practices to enhance pollinators compared with farmers of annual crops, who declared lesser intentions to apply pollinator-friendly management practices in the future. This difference might be related to the more intensive management required in annual crops (including repeated plowing and herbicide application in most cases), where farmers usually perceived that the implementation of pollinator-friendly practices might interfere with their management routines (Project Poll-Ole-GI, 2019). Another explanation might be related to historical links between farmers and permanent orchards, which usually generate a long-term sustainability perspective; such a perspective is absent in the case of annual herbaceous crops that can be replaced in the short term depending on market demands or subsidies.

Of note is the contrast between the scarce current application and the high willingness to adopt several management practices. This discrepancy has mostly been attributed by respondents to a lack of technical assistance and the scarcity of financial support from local or regional authorities for implementing pollinator-friendly practices (Project Poll-Ole-GI, 2019). Further, we cannot discard the potential existence of a “social desirability bias” that might have affected questionnaire administration, with farmers responding in the direction that they perceived to be desired by the investigator, thus showing high willingness to adopt pollinator-friendly practices in their fields.

4.3 What are the implications for the development of the Post-2020 CAP?

The Common Agricultural Policy (CAP) was designed to support European farmers and ensure Europe’s food security. However, today’s CAP focuses on more than just that, promoting a resilient and sustainable agricultural sector while contributing to ensure production of high-quality, safe and affordable food for its citizens and a strong socio-economic development in rural areas (European Commission, 2018).

The design of robust agricultural policies is paramount for pollinators’ conservation as agriculture intensification, through habitat loss, habitat fragmentation, and pesticide spraying effects, is considered the major driver of pollinator decline (Dicks et al., 2016). In this sense, the CAP introduced in its 2014 reform the concept of Ecological Focus Areas (EFAs), among other greening measures, with the aim of enhancing the ecological function of agricultural landscapes (Tzilivakis et al., 2016). During the period of 2014–2020, the CAP rules required farms with arable areas exceeding 15 hectares to dedicate 5% of such areas to ecologically beneficial elements, among which many pollinator-friendly management practices are included, such as fallow lands, hedges, and field margins. However, a clear mismatch between EFA design and implementation has been extensively reported, where most EFA options considered beneficial to biodiversity had low uptake among farmers (Underwood and Tucker, 2016; Pe'er et al., 2017).

Thus, incorporating farmers' perceptions into the 2021-2027 CAP agenda is fundamental, as farmers will be key and active actors in developing new strategies to focus investments toward the efficient delivery of pollination services in agricultural landscapes. Assessing farmers' perceptions and knowledge on this subject can help to explain farmers' attitudes towards political guidelines (Muoni et al., 2019). Furthermore, CAP greening measures should be adapted to the different socio-economic conditions and worldviews of farmers. Our results have shown the heterogeneity of perceptions among crop types and farmers in the different study sites, along with their different motivations and attitudes toward the application of pollinator-friendly practices.

In this regard, Kusnandar et al. (2019) highlighted three social factors to enhance farmers' participation in sustainable agricultural practices: empowerment (related to awareness of capability, decision making, ability to act, ability to self-organize, etc.); engagement (related to interaction among actors to communicate, common understanding, joint-decision making, etc.); and trust (related to quality of connections among actors). Incorporating these social factors into CAP political action is urgently needed to ensure the effective protection of pollinator diversity and enhance the provision of pollination services within agroecosystems. In this sense, it may be important to ensure that future CAP greening measures are designed according to the type of crop (permanent vs herbaceous), based on the differences observed in the present study regarding farmers' adoption of and willingness to adopt measures.

The ongoing Post-2020 reform of CAP (European Commission, 2018) offers a window of opportunity to focus on several critical points such as the needs to: (a) develop communication campaigns specifically designed for farmers and agricultural extension agents, to expand knowledge about pollinator-friendly management practices and their benefits in terms of ecosystem services like pollination and pest control; (b) provide financial support to promote those management practices farmers have shown higher willingness to adopt, given that successful implementation of practices will be highly dependent on their acceptance by farmers; and (c) strengthen technical advice by authorities and reduce administrative burdens in order to increase farmers' confidence and enhance the uptake of pollinator-friendly management practices that are cost-efficient and widely accepted (Pe'er et al., 2017).

Finally, coordination of the scientific, political, and social arenas is urgently needed to generate initiatives that can be used to reverse pollinator decline throughout European agroecosystems. The pollinator crisis is a challenging societal problem that involves many societal actors, including farmers and policy makers (Bartomeus and Dicks, 2019). Thus, integrating the knowledge and perception of farmers with scientific evidence on pollinators' roles in crops may provide the key to better understand how to respond to pollinator conservation problems in agricultural landscapes.

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Table 1. Socio-cultural characteristics of respondents for each study site.

Study site		**Asturias**	**Las Vegas**	**La Mancha**	**Murcia**
Dominant pollinator-dependent crops		**Cider-apple orchards**	**Horticultural crops**	**Sunflower crops**	**Mixed-fruit orchards**
Level of studies (% of respondents)	Primary	13.0	42.3	42.0	15.0
	Secondary	65.0	31.0	47.0	42.0
	University	22.0	26.7	11.0	43.0
Age of respondents (mean ± SD)		54.8±14.3	48.5±14.6	52±14.7	41.4±14.7
Gender (% of respondents)	Female	7.7	27.4	13.0	11.9
	Male	92.3	72.6	87.0	88.1
Main dedication (% of respondents)	Full-time farmers	13.3	35.4	41.5	23.9
	Part-time farmers	37.8	16.8	25.5	23.9
	Non-professional farmers	48.9	47.8	33.0	52.2
Main use of crop production (% of respondents)	Food self-supply	57.7	69.0	12.7	35.8
	Local direct market	74.4	35.4	53.2	11.9
	Large scale market	12.2	33.6	71.3	50.7
	Exchange/barter	2.2	7.9	0.0	2.9

Table 2. Parameters of the best multiple regression model to estimate the effect of socio-cultural factors on farmers' IPK.

Explanatory variables	**Parameters**	**Standard error**	**t**	**p-value**
Intercept	1.993	0.203	9.836	**< 0.0001**
Farmer's concern about pollinators	0.127	0.031	4.132	**< 0.0001**
Farmer's age	-0.091	0.046	-1.906	0.051
Farmer's education level	0.082	0.030	2.707	**0.007**
Full-time dedication to agriculture	0.097	0.034	2.849	**0.005**
Part-time dedication to agriculture	0.053	0.034	1.566	0.118

Figure captions

Figure 1. Study sites in Spain, with pictures illustrating the dominant agricultural landscapes. (Site A: cider-apple orchards in Asturias; site B: horticultural crops in Las Vegas; site C: sunflowers crops in La Mancha; site D: mixed-fruit orchards in Murcia).

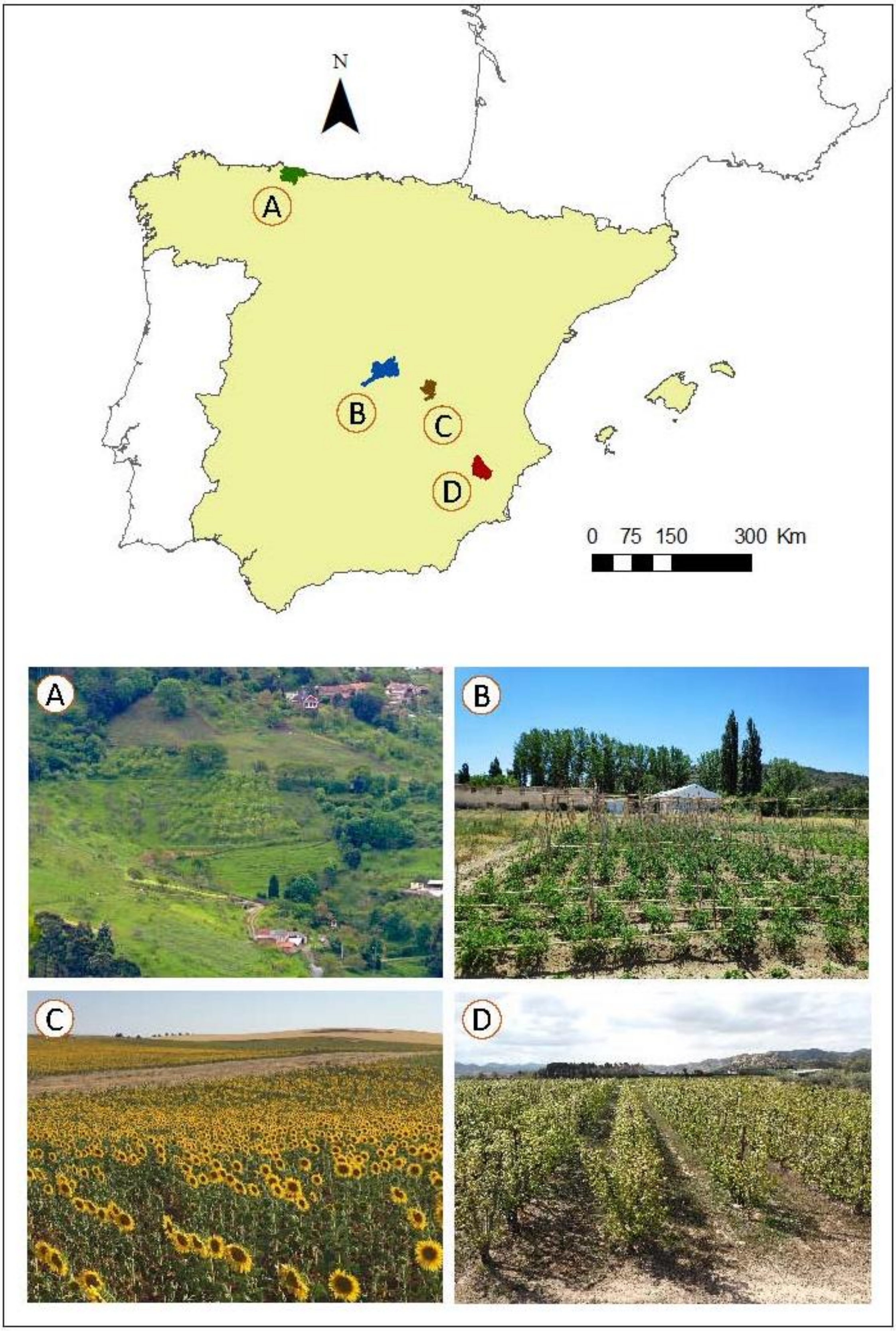
Figure 2. Farmers' perception on the roles of pollinators in their crops and the causes of pollinator decline: (A) average importance (0–5) attributed to different types of pollinators, according to the dominant crops in each study site; (B) importance attributed (0–4) to different drivers of pollinator decline.

Figure 3. Characterization of different agricultural practices as beneficial or harmful for pollinators according to farmers and the dominant crops in the corresponding study sites.

Figure 4. Farmers' pollination-knowledge indices. The boxes represent the three quartiles, and the whiskers represent the minimum and maximum values obtained for this variable. Circles are outlier values, and the asterisk is an extreme value. Different letters indicate significant differences for this variable (Tukey's tests, $P < 0.05$).

Figure 5. Redundancy analysis biplot (RDA). The biplot shows the relationships between implementing measures/practices (capital letters) to promote pollinators and variables related to farmers' characteristics. IPK: farmers' "index of pollination-knowledge".

Figure 6. Farmers' perception on the effectiveness and level of application of different management practices to promote pollinators. Among the farmers not currently applying each practice, the size of the ball indicates farmers' willingness to implement it in the future. (A: Cider-apple orchards in Asturias; B: horticultural crops in Las Vegas; C: sunflowers crops in La Mancha; D: mixed-fruit orchards in Murcia).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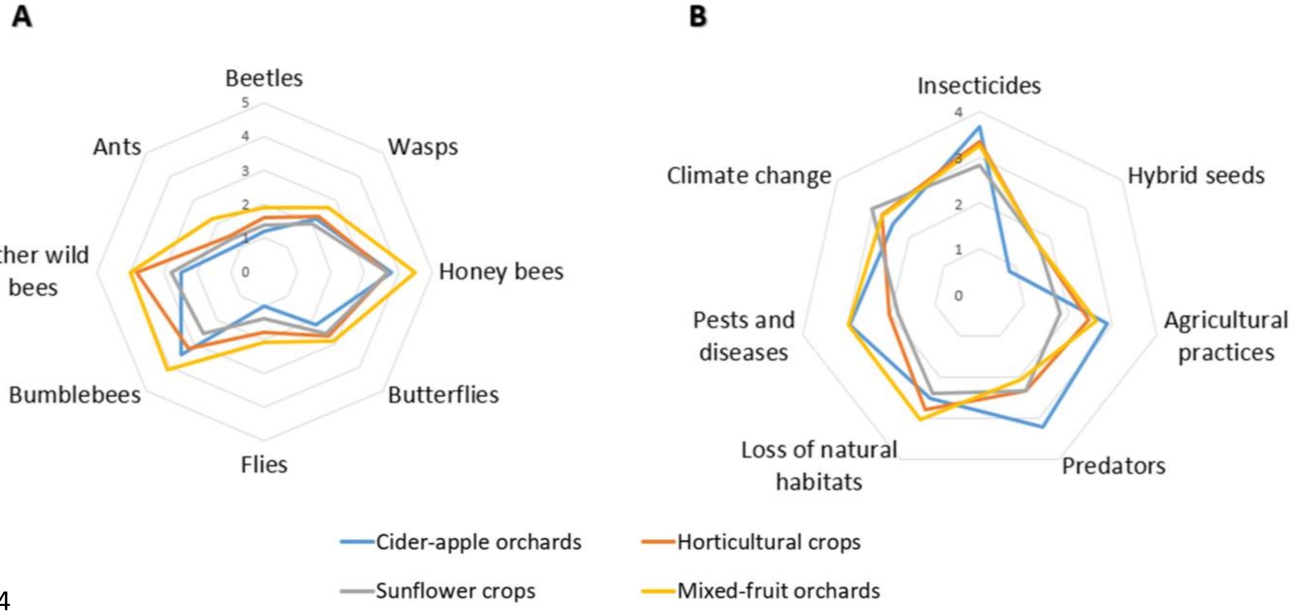
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Sunflower crops
Mixed-fruit orchards

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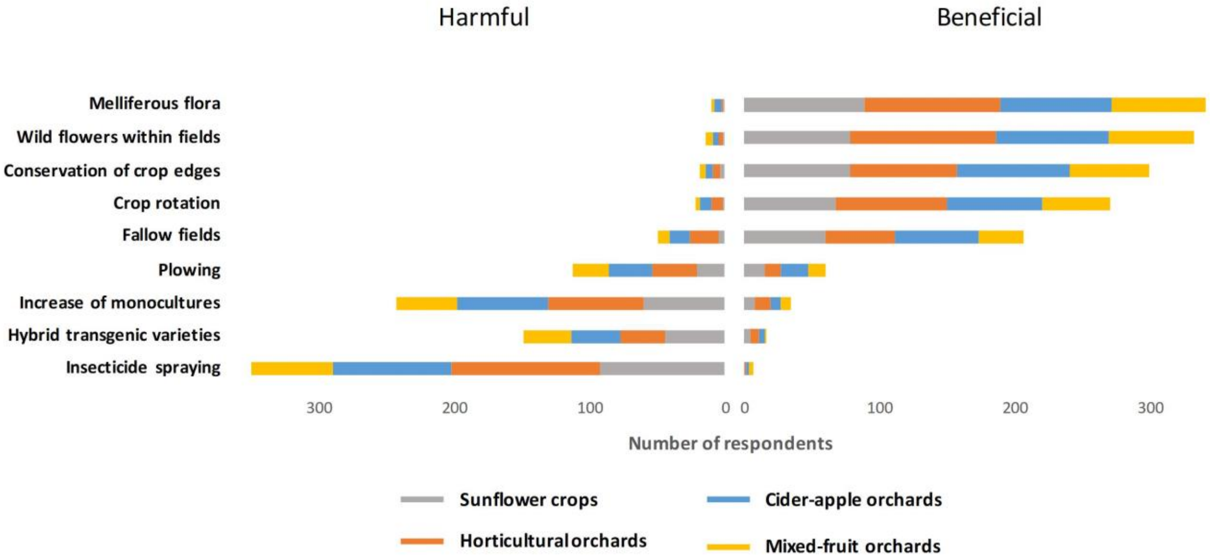

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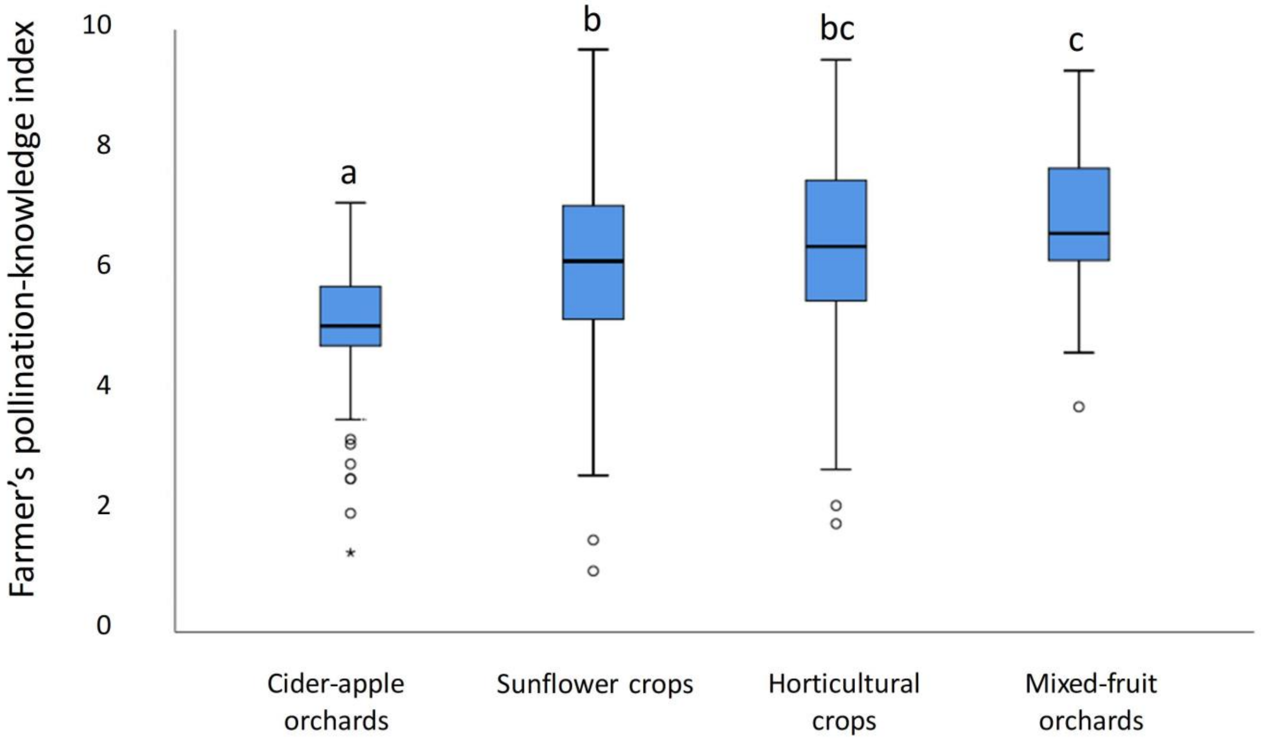
Farmer's pollination-knowledge index
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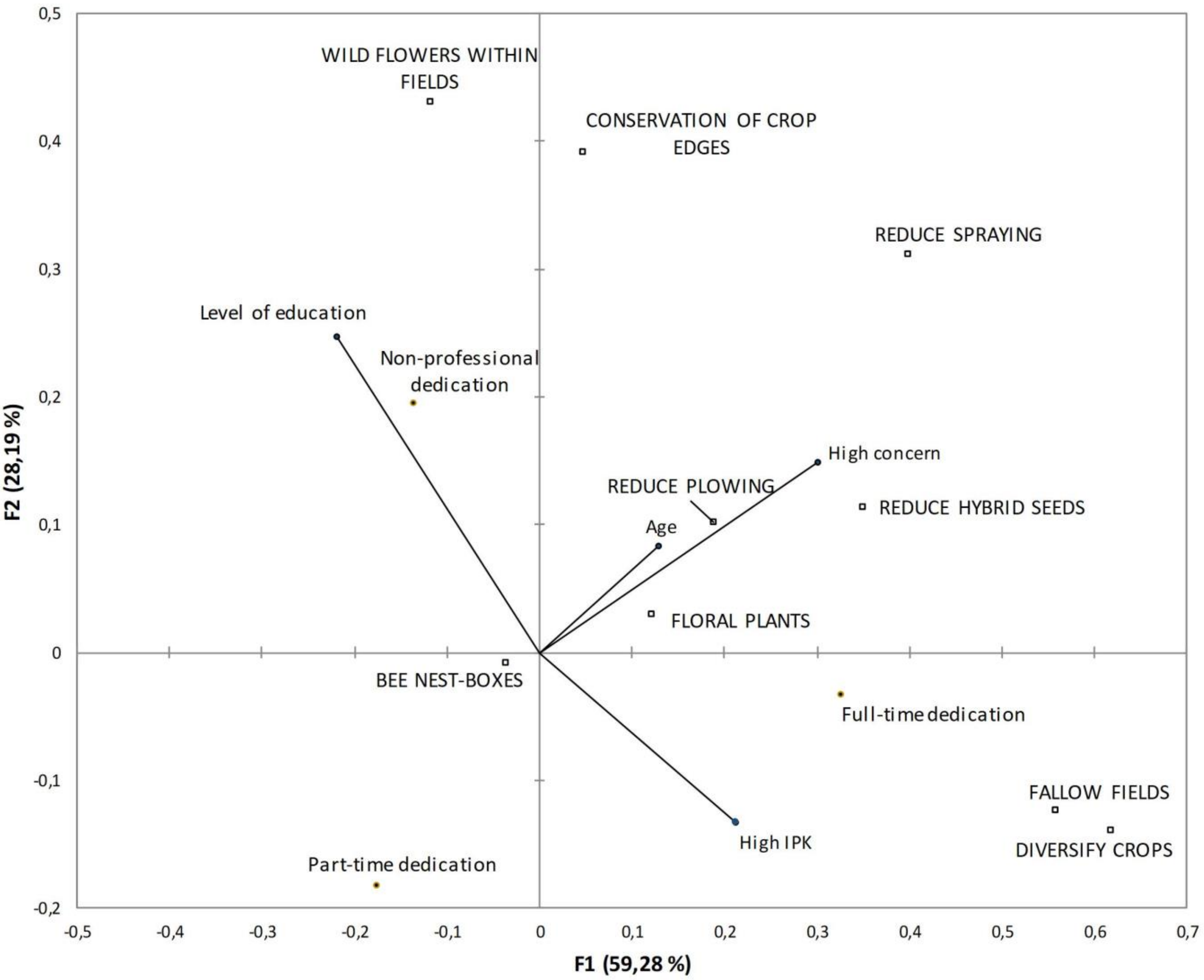
Sunflower crops
Horticultural crops
Mixed-fruit orchards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F2 (28,19 %)
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CONSERVATION OF CROP EDGES
REDUCE SPRAYING
Level of education
Non-professional dedication
High concern
REDUCE PLOWING
REDUCE HYBRID SEEDS
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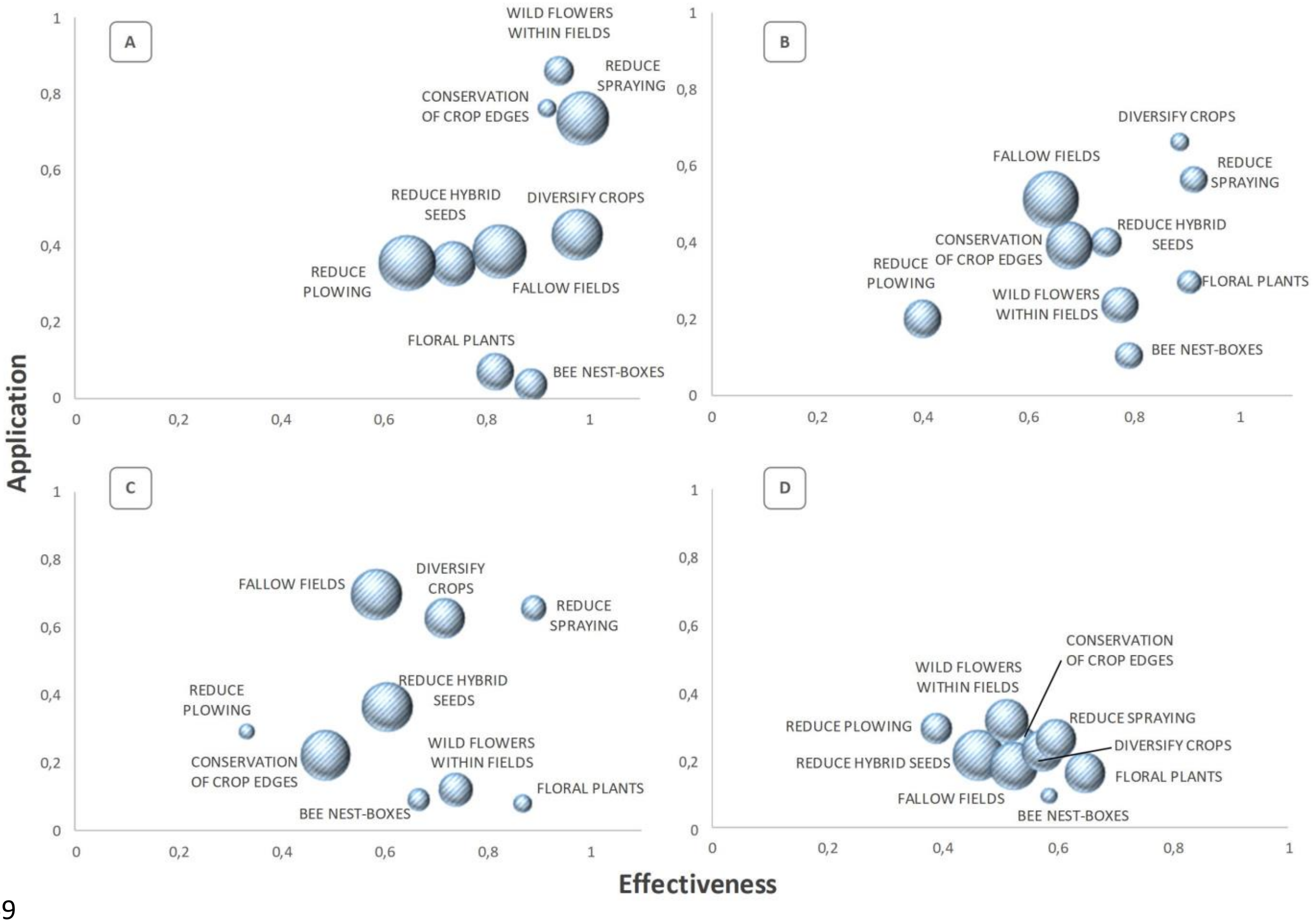
FLORAL PLANTS
BEE NEST-BOXES
Full-time dedication
FALLOW FIELDS
DIVERSIFY CROPS
High IPK
Part-time dedication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CONSERVATION OF CROP EDGES
REDUCE HYBRID SEEDS
DIVERSIFY CROPS
REDUCE PLOWING
FALLOW FIELDS
FLORAL PLANTS
BEE NEST-BOXES
DIVERSIFY CROPS
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REDUCE SPRAYING
REDUCE HYBRID SEEDS
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FLORAL PLANTS
WILD FLOWERS WITHIN FIELDS
BEE NEST-BOXES
FALLOW FIELDS
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REDUCE HYBRID SEEDS
CONSERVATION OF CROP EDGES
WILD FLOWERS WITHIN FIELDS
FLORAL PLANTS
BEE NEST-BOXES
CONSERVATION OF CROP EDGES
WILD FLOWERS WITHIN FIELDS
REDUCE SPRAYING
REDUCE PLOWING
DIVERSIFY CROPS
REDUCE HYBRID SEEDS
FLORAL PLANTS
FALLOW FIELDS
BEE NEST-BOXES

ABSTRACT

Pollinator conservation has become a key challenge to achieve sustainable agricultural landscapes and safeguard food supplies. Considering the potential negative effects of pollinator decline, international efforts have been developed to promote agri-environmental measures and pollinator-friendly management practices. However, little effort has been devoted to farmers' perceptions and knowledge about pollinators, or to farmers' role in enhancing pollination. We administered 376 face-to-face questionnaires in four areas of Spain with different dominant pollinator-dependent crops, to assess the factors behind farmers' perceptions, knowledge, and practices adopted to promote pollination. Overall, 92.7% of the respondents recognized that pollinator insects are necessary for crop production, and 73.4% perceived pollinator decline in their farms. We found that farmers had moderate knowledge about pollinators (6.1 ± 1.8, on a 1–10 scale). The most applied practices to promote pollinators were reducing insecticide spraying (53.2% of respondents), diversifying crops (42.8%), and increasing fallow fields (39.1%). Factors such as education, age, concern about the pollinator crisis, and professional dedication to agriculture strongly influenced farmers' knowledge and current application of pollinator-friendly practices. Implications of our results for the ongoing reform of the Common Agricultural Policy are discussed, highlighting the need to increase engagement and trust of farmers through communication and technical assistance.

KEYWORDS: cider-apple orchards; farmers' perception; horticultural crops; pear orchards; pollination; sunflower crops; sustainable agroecosystems

1. Introduction

Maintaining pollination services to assure present and future food production is currently a major challenge in the design of sustainable agroecosystems (Bartomeus and Dicks, 2019). Insect pollinators contribute to the productivity of more than 75% of important crop species (Klein et al., 2007; Kluser et al., 2010), representing 35% of the global crop production volume (IPBES, 2016). Globally, the agricultural production directly attributed to animal-mediated pollination has an estimated annual market value of US$ 235–577 billion worldwide (Archer et al., 2018; Gallai et al., 2009).

Furthermore, pollinators are inextricably linked to human well-being through the maintenance of wild plant reproduction and the safeguarding of ecosystem health and function (Kleijn et al., 2015; Potts et al., 2016). Pollinators underpin sustainable livelihoods that link ecosystems, cultural values, and customary governance systems across the world (Hill et al., 2019). Thus, conservation of pollinators has become crucial for advancing United Nations Sustainable Development Goals (Wood and DeClerck, 2015).

In recent years, several studies have reported important declines of different pollinator taxa (Biesmeijer et al., 2006; Potts et al., 2010; IPBES, 2016), including reductions in the abundance and diversity of wild bees in Europe, mainly attributed to anthropogenic drivers such as habitat fragmentation, agricultural intensification, and climate change (Biesmeijer et al., 2006; Potts et al., 2010). The intensification of agricultural landscapes in particular has reduced habitat diversity and availability (Tscharntke et al., 2005), which threatens wild bee populations that are strongly dependent on natural and semi-natural habitats (Saturni et al., 2016). Where “Red Lists” of Endangered Species are available, it has been estimated that more than 40% of wild bee species could be threatened (IPBES, 2016).

Critical voices from the scientific and political arenas have called for maintaining sustainable and healthy insect pollination (Gill et al., 2016). Global concern about the fate of pollinators has resulted in several continental, national, and regional programs intended to tackle pollinator declines (Potts et al., 2010). Considering the potential repercussions on agricultural productivity, the European Union has proposed a series of management practices to promote pollinator conservation and enhance pollination services (Scheper et al., 2013). These practices include support for diversified farming systems, maintenance of permanent grasslands, and protection of particular landscape features (Scheper et al., 2013; Dicks et al., 2016).

Understanding farmers' perceptions of the role of pollinators and the practices adopted to promote them is essential and highly relevant to influence the way farmers manage their farms and participate in the implementation of agri-environmental measures (Herzon and Mikk, 2007; Meijer et al., 2015; Wilson and Hart, 2000). Sustainable agroecosystems should support biodiversity conservation and food production, and incorporation of farmers' local knowledge and perceptions is essential to achieve both goals (Rawluk and Saunders, 2019). However, most research about pollination to date has focused on ecological studies of pollinators (e.g., Nicholson et al., 2017; Steffan-Dewenter et al., 2005) or on the their economic contributions to crop productivity and/or sustainability (e.g., Allsopp et al., 2008). Further research is needed to understand farmers' perceptions and knowledge about the contributions provided by insect pollinators within agroecosystems (Smith and Sullivan, 2014). In a recent literature review, Rawluk and Saunders (2019) found an important gap in research on these topics, with only four papers exploring local knowledge on insect-provided pollination service. This represents an important limitation for the effective implementation of agri-environmental schemes to safeguard pollination services. As farmers are the ultimate managers of the agricultural landscape at the local and regional scale, it is essential to understand their perceptions to design innovative and sustainable solutions applied from a science–management–practice perspective.

In this research, we focus on several pollinator-dependent crops of high economic relevance in Spain, cider-apple orchards, mixed-fruit (mostly pear) orchards, sunflower crops, and horticultural crops (mostly tomato, pepper, cucumber, and melon), to tackle three specific goals: (1) assess farmers' perception and knowledge about the role of pollinators in their crops; (2) explore which sociocultural factors influence the perception and knowledge of farmers about pollinators and pollination service; and (3) analyze farmers' current adoption and future willingness to adopt agricultural practices that promote pollinator conservation and enhance pollination.

2. Methods

2.1 Study sites

We selected four study sites in Spain where the agricultural landscape is dominated by crops highly dependent on insect pollinators for seed or fruit production, and that are also relevant in economic terms (Fig. 1).

The Asturias study site (Fig. 1A) comprises six municipalities that represent the most important area for cider-apple (*Malus x domestica* Borkh) production in Spain, with around 10,000 ha devoted to this crop (INDUROT, 2010). Cider-apple orchards are frequently surrounded by natural hedgerows and embedded in a mosaic landscape that comprises multiple land cover types, such as livestock pastures, eucalyptus plantations, native forests, and heathlands. Cider-apple orchards are based on disease-resistant cultivars and low-input management, with low use of machinery and scarce use of chemicals (no fungicides, few pesticides, and herbicides restricted to areas under trees).

The study site of Las Vegas (Fig. 1B) is a rural district comprising 23 municipalities located in the south-eastern part of the Madrid region with an economy traditionally based on the farming sector and associated agri-food industries. The agricultural landscape is characterized by the presence of fluvial terraces with horticultural (mostly tomato, pepper, cucumber, and melon) and cereal crops, occupying nearly 53,000 ha. Olive groves and vineyards are also grown in lightly sloped soils with low levels of organic material (Pérez-Ramírez et al., 2019).

The study site of La Mancha (Fig. 1C) comprises nine municipalities in the Province of Cuenca. The agricultural landscape is dominated by non-irrigated cereals and oilseed sunflowers cultivated under an annual rotation regime, occupying nearly 31,600 ha. This area is one of the most important producers of sunflower oil in Spain. Sunflowers are farmed under an intensive regime that includes the use of herbicides and various types of fertilizers.

The Murcia study site (Fig. 1D) comprises the municipality of Jumilla, with a landscape composed of 64% of cultivated area, some residual holm oaks, and formations of Aleppo pine (*Pinus halepensis*) with Mediterranean scrublands. The dominant crops are vines, olives, almonds, pears, and peaches. Particularly, pear orchards occupy nearly 1,200 ha; Jumilla is the largest producer of the Ercolini cultivar both in Spain and in Europe, producing almost 22,000 tons annually (48% and 24% of national and European production respectively).

2.2 Data collection

A total of 376 direct face-to-face standardized questionnaires were conducted in the study areas (90 questionnaires in the cider-apple orchards of Asturias, 116 in horticultural crops of the Las Vegas district, 103 in the sunflower crops of La Mancha, and 67 in the mixed-fruit orchards of Jumilla), from January to September 2018. The sampled population was restricted to individuals over 18 years old whose activity was linked to the agricultural sector. Agricultural extension offices, municipalities, and public areas (e.g., public parks, snack bars, and town squares) were used to find farmers in each of the study sites. Snow-ball sampling technique (Bernard, 2005; Bryman, 2012) was then used to locate new farmers and people with farming-related jobs (e.g., agroindustry professionals, members of farmers' unions or cooperatives, and local development agents). Based on the sample size and the total number of registered farmers of each study area, the sampling errors at the 95% confidence level were estimated as ±9.0% in Asturias, ±9.5% in La Mancha, ±9.7% in Madrid, and ±10.0% in Murcia. More details about the sampled population are provided in Table 1.

The survey began with a brief introduction explaining the purpose of the study. Then, respondents were asked about their perceptions and knowledge of pollination services in their farms, following a questionnaire structured into four major sections: (1) knowledge about pollinators and their role in crop production (specifically, respondents were asked about the roles of beetles, wasps, honeybees, butterflies, flies, bumblebees, other wild bees, and ants); (2) perception of the conservation status of pollinators and the drivers of change currently affecting them; (3) main practices currently implemented in their fields, and willingness to adopt other management practices to promote pollinators, with specific questioning about their perception on the beneficial or harmful effect of the different practices; and (4) socio-cultural characteristics (i.e., place of residence, formal education, age, gender, and dedication). More details on the structure and the different questions that formed the questionnaire are provided in Appendix A. Two questionnaire models were used, with the question order changed to avoid any sequence effects (García-Llorente et al., 2012).

2.3 Data analysis

We performed frequency analyses on farmers' perception of: (a) the pollination dependency of their crops, (b) the importance of different pollinator taxa for crop pollination, (c) the status and trends of pollinators and current drivers of change, and (d) the beneficial and harmful effects of different agricultural management practices on pollinators. To analyze farmers' knowledge of pollinators and the role of pollinators in their crops, we built an "index of pollination knowledge" (IPK) by comparing the responses of farmers to four questions of the questionnaire with the answers to the same questions provided by experts in the field from each of the different study sites (see Appendix B). The IPK ranged from 0 to 10, with higher values indicating knowledge more concordant with the experts' criteria. ANOVA tests were performed to test the differences in farmers' pollination knowledge between the four study sites.

A stepwise multiple regression was performed to uncover socio-cultural factors that better explained farmers' knowledge (IPK) about the importance of pollinators for their crops. Five independent socio-cultural variables were used to build the model. The Akaike information criterion (AIC) was used to select the most parsimonious model.

Finally, we performed a redundancy analysis (RDA) to explore farmers' adoption of management practices to promote pollinators (dependent variables) and the socio-cultural factors influencing that adoption (explanatory variables). A Monte Carlo permutation test (1,000 permutations) was performed to determine the significance of explanatory variables in determining farmer's adoption of pollinator-friendly practices. All analyses were performed with the XLSTAT software (Addinsoft, France).

3. Results

3.1 Farmers' perception of the status and roles of pollinators in their crops

Overall, 92.7% of the respondents recognized that pollinator insects are necessary for food production, ranging from 88% in farmers of sunflower crops to 95% in farmers of mixed-fruit orchards. Farmers in the four study sites clearly identified honeybees as the main pollinators of their crops, followed by bumblebees and other wild bees (Fig. 2A). The role of bumblebees was particularly highlighted in the case of cider-apple and mixed-fruit orchards, whereas the role of other wild bees was highlighted in mixed-fruit orchards and horticultural crops. Other potential pollinators (e.g., flies, butterflies, beetles) were considered less relevant by respondents in the four study sites (Fig. 2A).

Overall, 73.4% of the respondents perceived that pollinators have declined in their farms, ranging from 58.2% of respondents in mixed-fruit orchards of Murcia, to 82.5% in sunflower crops of La Mancha. Farmers' perceptions on the causes of this decline differed slightly among study sites (Fig. 2B), although most farmers consistently perceived the use of insecticides, climate change, and the loss of natural habitats as the most relevant drivers behind pollinators' decline. In the case of cider-apple farmers, the roles of predators and agricultural practices were also highlighted. In addition, pests and diseases (e.g., *Varroa* mite, viruses, fungi) were considered to be important causes of pollinator decline by cider-apple and mixed-fruit farmers.

Finally, regarding farmers' perceptions on the beneficial and harmful effects of different agricultural practices on pollinators, results were highly consistent among the four study areas (Fig. 3). Farmers consistently perceived as beneficial to pollinators the sowing of melliferous flora (97.15% of respondents), maintenance of wildflowers within fields (94.6%), conservation of natural or semi-natural field edges (85.2%), crop rotations (77.2%), and fallow fields (60%). In contrast, insecticide spraying (97.7%) and monocultures (90%) were considered to be the most harmful practices for pollinators, followed by the use of hybrid transgenic varieties (83%) (Fig. 3). Although not very important, the role of plowing seemed more controversial, with some farmers considering it harmful (31.0%) and others beneficial (17.1%).

3.2 Farmers' knowledge about pollinators and their role in crop production

Farmers' IPK (ranging from 0 to 10) showed a mean value of 6.11 (SD= 1.8) for the whole sample, which indicates a medium level of knowledge among respondents. However, significant differences were observed between sites ($F = 25.836$; d.f. = 3; $P < 0.001$; Fig. 4); farmers of cider-apple orchards in Asturias showed significantly lower IPK values (mean = 5.06; SD = 1.16), and farmers of mixed-fruit trees in Murcia showed higher values (mean = 7.20; SD = 1.39).

Regarding the factors influencing farmers' knowledge about pollination, the most parsimonious regression model showed that the IPK was positively related to the farmer's education level, concern about the pollinator crisis, and professional dedication to agriculture, whereas it was negatively related to age ($F = 10.035$; d.f. = 5; $P < 0.001$) (Table 2).

3.3 Farmers' current adoption and willingness to adopt management practices to promote pollinators

Overall, 75.5% of the respondents were currently adopting at least one management practice to promote pollinators. Specifically, the management practices most applied by farmers to promote pollinators in their fields were reducing insecticide spraying (53.2% of respondents), diversifying crops (42.8%), and increasing the number of fallow fields (39.1%).

RDA revealed associations between several socio-cultural characteristics of the farmers and the adoption of different measures to protect pollinators (Fig. 5). The first axis of the RDA (59.28% of the variance) showed that full-time dedication to farming and degree of concern about pollinators were related to implementing fallow fields, diversifying crops, and reducing plowing and hybrid seeds. The second axis of the RDA (28.19% of the variance) revealed that a high level of education was mainly associated with three practices to promote pollinators: maintaining wildflowers within fields, reducing spraying, and conserving crop edges.

Respondents associated with each crop type showed different patterns in current application, perception of effectiveness, and willingness to adopt management practices to promote pollinators. Cider-apple orchard farmers considered all the proposed practices to promote pollinators quite effective, but only three of these practices were highly applied in this study area (wildflowers within fields, reduced spraying, and conservation of crop edges). Further, cider-apple orchard farmers not currently applying pollinator-friendly practices showed high willingness to adopt many of the proposed management practices, except for the conservation of crop edges (Fig. 6A).

Farmers of horticultural crops in Las Vegas considered diversifying crops, reducing spraying, and installing floral plants within their fields to be the most effective practices for pollinators; reducing spraying, diversifying crops, and increasing the number of fallow fields were the most commonly currently applied practices. Further, respondents not currently applying pollinator-friendly practices in this study site only showed high willingness to increase the number of fallow fields and conserve crop edges in their fields (Fig. 6B).

Sunflower farmers considered the reduction of spraying and installing floral plants within their fields to be the most effective practices to favor pollinators; reducing spraying, diversifying their crops, and increasing the number of fallow fields were currently the most applied practices. The sunflower farmers showed a high willingness to adopt practices such as conserving crop edges, reducing the use of hybrid seeds, and increasing the number of fallow fields (Fig. 6C).

Farmers of mixed-fruit orchards in Murcia considered sowing floral plants and reducing spraying to be the most effective practices for pollinators; the reduction of plowing and the maintenance of wildflowers within fields were the most applied practices. Most respondents showed high willingness to adopt several other management practices, with the exception of increasing the installation of nest-boxes for bees (Fig. 6D).

4. Discussion

4.1 Farmers' perception and knowledge of pollinators and their role in crops

Previous studies have indicated a widespread perception among farmers of pollinators' importance for their crops (Gaines-Day et al., 2017; Hanes et al., 2013; Park et al., 2018). Conversely, other studies have shown that farmers were not aware of the role of pollinators, even in the case of pollinator-dependent crops (Kasina et al., 2009; Munyuli, 2011). Lack of awareness seems particularly prevalent regarding the role of solitary wild bees, whose relevance is frequently underrated by farmers (Smith et al., 2017). Our results show that farmers associated with four different pollinator-dependent crops in Spain were able to identify the main pollinators of their crops, and most farmers, regardless of the study area, were well aware that pollinator insects are necessary for crop production.

Remarkably, we found greater appreciation for honeybees as valuable pollinators among all respondents, which is in line with previous scientific evidence that has recognized the honeybee as the single most important species for crop pollination (Geldmann et al., 2018; Klein et al., 2007). However, the important role of wild bees (Garibaldi et al., 2013), particularly bumblebees (Eeraerts et al., 2020; Garibaldi et al., 2013), in enhancing pollination is not always well perceived by farmers. We found that farmers of horticultural crops and mixed-fruit orchards perceived an important role of bumblebees and other wild bees, whereas farmers of sunflower crops and cider-apple orchards perceived this role as less relevant. In the case of cider-apple orchards, it is interesting to note that farmers also perceived bumblebees and honeybees as the main pollinators of their crops, whereas previous studies have shown low pollinating efficiency of honeybees in apple orchards (Blitzer et al., 2016; Miñarro and García, 2018; Vicens and Bosch, 2000). In general, farmers’ knowledge about the real pollination efficiency of wild bees appears to be somewhat limited (Holzschuh et al., 2012).

Regarding pollinators’ status and trends, our results show that farmers perceived a decline in the number of pollinators in their farms, which is in line with current scientific evidence (IPBES, 2016). Most farmers perceived insecticide use, climate change, and loss of natural habitats as the most relevant causes of pollinators’ decline. Predators and pest diseases (e.g., *Varroa* mite, viruses, fungi; IPBES, 2016) were also pointed out as important causes of decline, but only in permanent orchards. These findings reveal fairly good knowledge among farmers of the major drivers of the pollinator crisis identified at the European level over the past decades (Archer et al., 2018; Sánchez-Bayo and Wyckhuys, 2019). These current trends are altering not only pollination service, but also other important services such as natural pest control and nutrient recycling (Aizen et al., 2009), which, in turn, may have negative effects on crop production (Zhang et al., 2007).

Regarding the socio-cultural factors that influence farmers' knowledge about pollinators and pollination, our results reveal that full dedication to agriculture and higher education level are associated with a higher degree of concern and better knowledge. Contrarily, farmer age was negatively related with pollination-knowledge, probably due to the lower education level of older farmers. Gender did not have a significant influence on pollination-knowledge, although our sample was largely skewed toward men. In general, the observed trends are consistent with previous studies in other intensive agroecosystems, which found that older farmers are less willing to change management practices, while more educated farmers are more aware and willing to adopt conservation schemes (Ahnström et al., 2009).

4.2 What are farmers doing and willing to do to promote pollinators?

To maintain adequate pollination service by wild bees, it is essential to provide foraging and nesting sites in the agricultural landscape (Schulp et al., 2014). Predominant agricultural practices (e.g., plowing and pesticide application) usually make intensive crops unsuitable permanent habitats for wild bees (Holzschuh et al., 2012). Focusing on the protection of pollinators and enhancing pollination, European agri-environmental schemes have promoted several pollinator-friendly practices (e.g., flowering hedgerows, fallow fields, conserving crop edges) (Kremen and Miles, 2012; M'Gonigle et al., 2015; Wood et al., 2015). Recent studies suggest that leaving land fallow is one of the most promising approaches for supporting and enhancing biodiversity in agro- ecosystems

(Robleño et al., 2018). Maintaining strips of natural or semi-natural elements (e.g., herbaceous plants, hedgerows or bushes) between adjacent fields has also been identified as a positive practice to enhance pollinator conservation in intensive agricultural landscapes.

However, our results show that current application of management practices to promote pollinators was still scarce in our study sites, and that not all pollinator-friendly practices were well accepted by farmers. In permanent orchards (e.g., cider-apple orchards and mixed-fruit orchards), we found that the agricultural practices most commonly applied were the maintenance of wildflowers within fields, reducing spraying, and conservation of crop edges. In contrast, in herbaceous crops (e.g., horticultural and sunflower crops), reducing spraying, diversifying crops, and increasing the number of fallow fields were currently the most applied practices. These different trends in implementing pollinator-friendly practices may respond to the distinct management requirements of each crop type (permanent vs. annual crops).

Despite the low current application, farmers showed relatively high willingness to adopt management practices to promote pollinators, but with differences among crop types. Our results show two major trends that correspond to the above-mentioned crop types. Farmers of permanent crops were much more willing to apply several practices to enhance pollinators compared with farmers of annual crops, who declared lesser intentions to apply pollinator-friendly management practices in the future. This difference might be related to the more intensive management required in annual crops (including repeated plowing and herbicide application in most cases), where farmers usually perceived that the implementation of pollinator-friendly practices might interfere with their management routines (Project Poll-Ole-GI, 2019). Another explanation might be related to historical links between farmers and permanent orchards, which usually generate a long-term sustainability perspective; such a perspective is absent in the case of annual herbaceous crops that can be replaced in the short term depending on market demands or subsidies.

Of note is the contrast between the scarce current application and the high willingness to adopt several management practices. This discrepancy has mostly been attributed by respondents to a lack of technical assistance and the scarcity of financial support from local or regional authorities for implementing pollinator-friendly practices (Project Poll-Ole-GI, 2019). Further, we cannot discard the potential existence of a “social desirability bias” that might have affected questionnaire administration, with farmers responding in the direction that they perceived to be desired by the investigator, thus showing high willingness to adopt pollinator-friendly practices in their fields.

4.3 What are the implications for the development of the Post-2020 CAP?

The Common Agricultural Policy (CAP) was designed to support European farmers and ensure Europe’s food security. However, today’s CAP focuses on more than just that, promoting a resilient and sustainable agricultural sector while contributing to ensure production of high-quality, safe and affordable food for its citizens and a strong socio-economic development in rural areas (European Commission, 2018).

The design of robust agricultural policies is paramount for pollinators’ conservation as agriculture intensification, through habitat loss, habitat fragmentation, and pesticide spraying effects, is considered the major driver of pollinator decline (Dicks et al., 2016). In this sense, the CAP introduced in its 2014 reform the concept of Ecological Focus Areas (EFAs), among other greening measures, with the aim of enhancing the ecological function of agricultural landscapes (Tzilivakis et al., 2016). During the period of 2014–2020, the CAP rules required farms with arable areas exceeding 15 hectares to dedicate 5% of such areas to ecologically beneficial elements, among which many pollinator-friendly management practices are included, such as fallow lands, hedges, and field margins. However, a clear mismatch between EFA design and implementation has been extensively reported, where most EFA options considered beneficial to biodiversity had low uptake among farmers (Underwood and Tucker, 2016; Pe'er et al., 2017).

Thus, incorporating farmers' perceptions into the 2021-2027 CAP agenda is fundamental, as farmers will be key and active actors in developing new strategies to focus investments toward the efficient delivery of pollination services in agricultural landscapes. Assessing farmers' perceptions and knowledge on this subject can help to explain farmers' attitudes towards political guidelines (Muoni et al., 2019). Furthermore, CAP greening measures should be adapted to the different socio-economic conditions and worldviews of farmers. Our results have shown the heterogeneity of perceptions among crop types and farmers in the different study sites, along with their different motivations and attitudes toward the application of pollinator-friendly practices.

In this regard, Kusnandar et al. (2019) highlighted three social factors to enhance farmers' participation in sustainable agricultural practices: empowerment (related to awareness of capability, decision making, ability to act, ability to self-organize, etc.); engagement (related to interaction among actors to communicate, common understanding, joint-decision making, etc.); and trust (related to quality of connections among actors). Incorporating these social factors into CAP political action is urgently needed to ensure the effective protection of pollinator diversity and enhance the provision of pollination services within agroecosystems. In this sense, it may be important to ensure that future CAP greening measures are designed according to the type of crop (permanent vs herbaceous), based on the differences observed in the present study regarding farmers' adoption of and willingness to adopt measures.

The ongoing Post-2020 reform of CAP (European Commission, 2018) offers a window of opportunity to focus on several critical points such as the needs to: (a) develop communication campaigns specifically designed for farmers and agricultural extension agents, to expand knowledge about pollinator-friendly management practices and their benefits in terms of ecosystem services like pollination and pest control; (b) provide financial support to promote those management practices farmers have shown higher willingness to adopt, given that successful implementation of practices will be highly dependent on their acceptance by farmers; and (c) strengthen technical advice by authorities and reduce administrative burdens in order to increase farmers' confidence and enhance the uptake of pollinator-friendly management practices that are cost-efficient and widely accepted (Pe'er et al., 2017).

Finally, coordination of the scientific, political, and social arenas is urgently needed to generate initiatives that can be used to reverse pollinator decline throughout European agroecosystems. The pollinator crisis is a challenging societal problem that involves many societal actors, including farmers and policy makers (Bartomeus and Dicks, 2019). Thus, integrating the knowledge and perception of farmers with scientific evidence on pollinators' roles in crops may provide the key to better understand how to respond to pollinator conservation problems in agricultural landscapes.

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Table 1. Socio-cultural characteristics of respondents for each study site.

Study site		**Asturias**	**Las Vegas**	**La Mancha**	**Murcia**
Dominant pollinator-dependent crops		**Cider-apple orchards**	**Horticultural crops**	**Sunflower crops**	**Mixed-fruit orchards**
Level of studies (% of respondents)	Primary	13.0	42.3	42.0	15.0
	Secondary	65.0	31.0	47.0	42.0
	University	22.0	26.7	11.0	43.0
Age of respondents (mean ± SD)		54.8±14.3	48.5±14.6	52±14.7	41.4±14.7
Gender (% of respondents)	Female	7.7	27.4	13.0	11.9
	Male	92.3	72.6	87.0	88.1
Main dedication (% of respondents)	Full-time farmers	13.3	35.4	41.5	23.9
	Part-time farmers	37.8	16.8	25.5	23.9
	Non-professional farmers	48.9	47.8	33.0	52.2
Main use of crop production (% of respondents)	Food self-supply	57.7	69.0	12.7	35.8
	Local direct market	74.4	35.4	53.2	11.9
	Large scale market	12.2	33.6	71.3	50.7
	Exchange/barter	2.2	7.9	0.0	2.9

Table 2. Parameters of the best multiple regression model to estimate the effect of socio-cultural factors on farmers' IPK.

Explanatory variables	**Parameters**	**Standard error**	**t**	**p-value**
Intercept	1.993	0.203	9.836	**< 0.0001**
Farmer's concern about pollinators	0.127	0.031	4.132	**< 0.0001**
Farmer's age	-0.091	0.046	-1.906	0.051
Farmer's education level	0.082	0.030	2.707	**0.007**
Full-time dedication to agriculture	0.097	0.034	2.849	**0.005**
Part-time dedication to agriculture	0.053	0.034	1.566	0.118

Figure captions

Figure 1. Study sites in Spain, with pictures illustrating the dominant agricultural landscapes. (Site A: cider-apple orchards in Asturias; site B: horticultural crops in Las Vegas; site C: sunflowers crops in La Mancha; site D: mixed-fruit orchards in Murcia).

Figure 2. Farmers' perception on the roles of pollinators in their crops and the causes of pollinator decline: (A) average importance (0–5) attributed to different types of pollinators, according to the dominant crops in each study site; (B) importance attributed (0–4) to different drivers of pollinator decline.

Figure 3. Characterization of different agricultural practices as beneficial or harmful for pollinators according to farmers and the dominant crops in the corresponding study sites.

Figure 4. Farmers' pollination-knowledge indices. The boxes represent the three quartiles, and the whiskers represent the minimum and maximum values obtained for this variable. Circles are outlier values, and the asterisk is an extreme value. Different letters indicate significant differences for this variable (Tukey's tests, $P < 0.05$).

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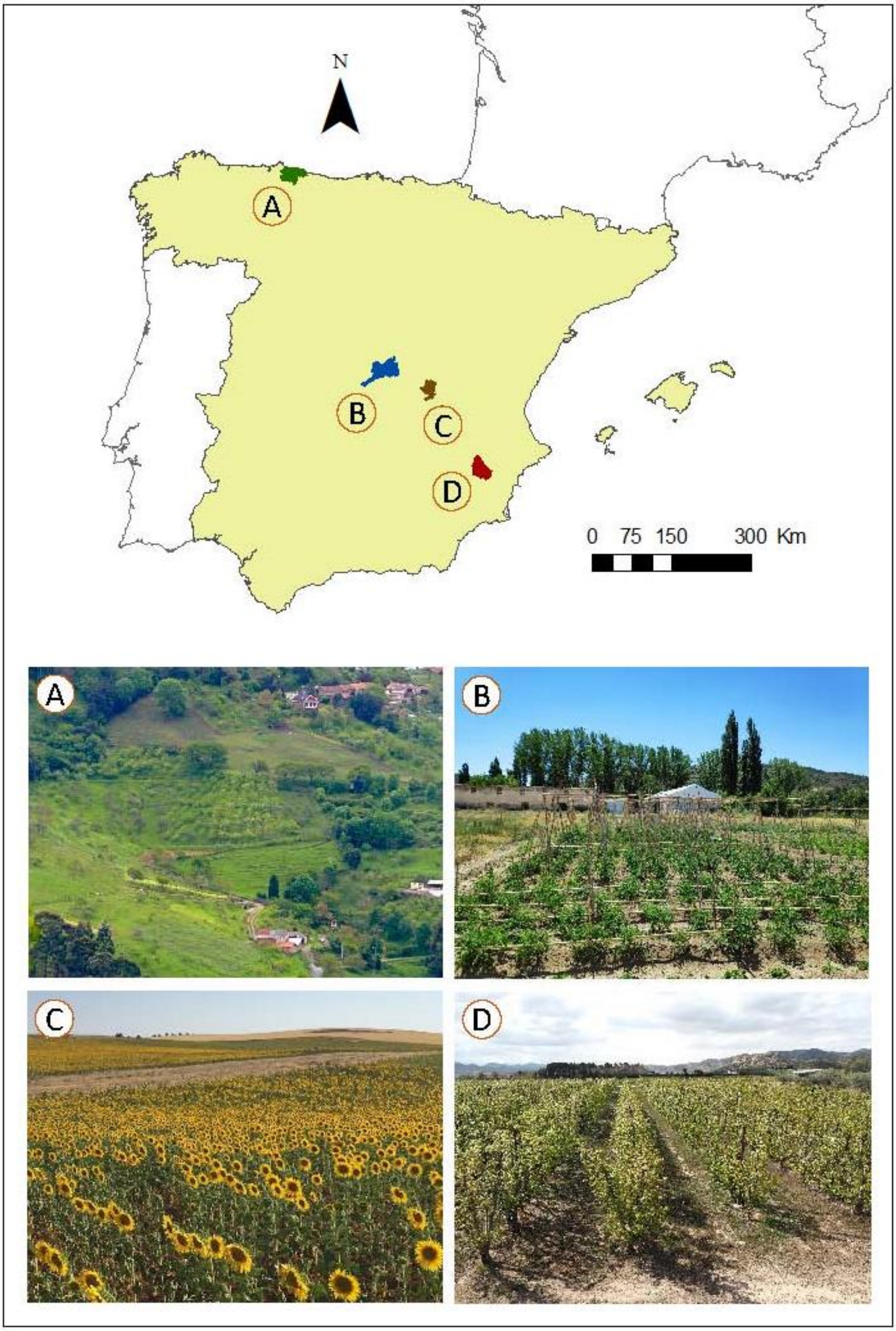
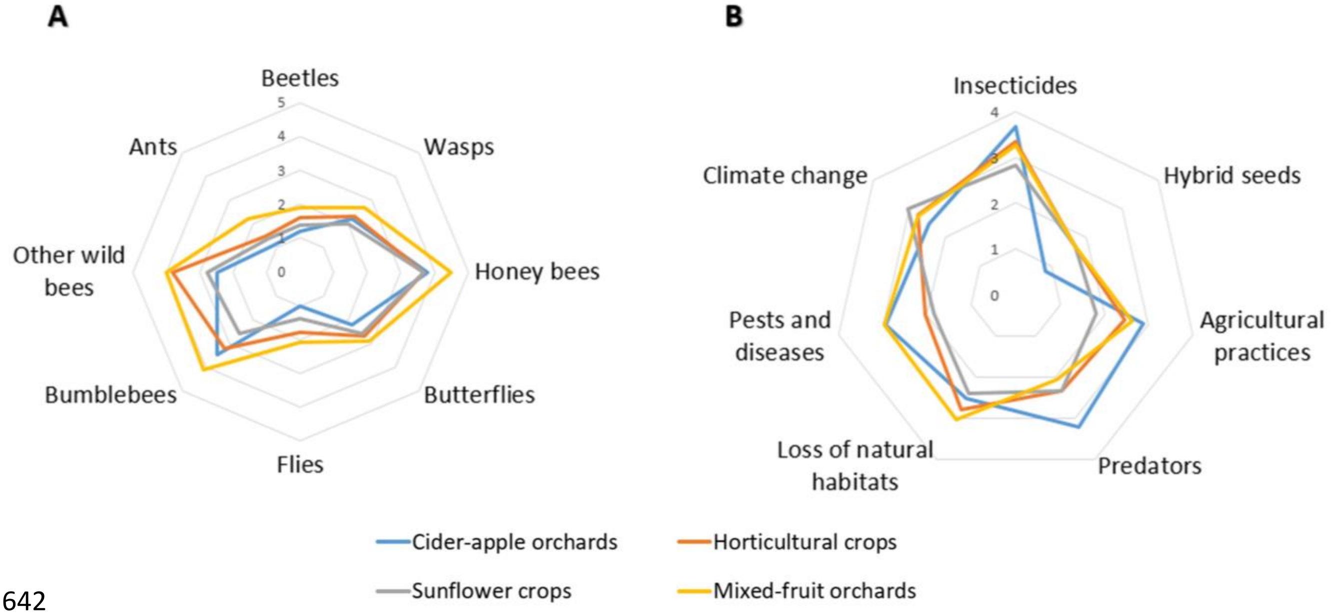
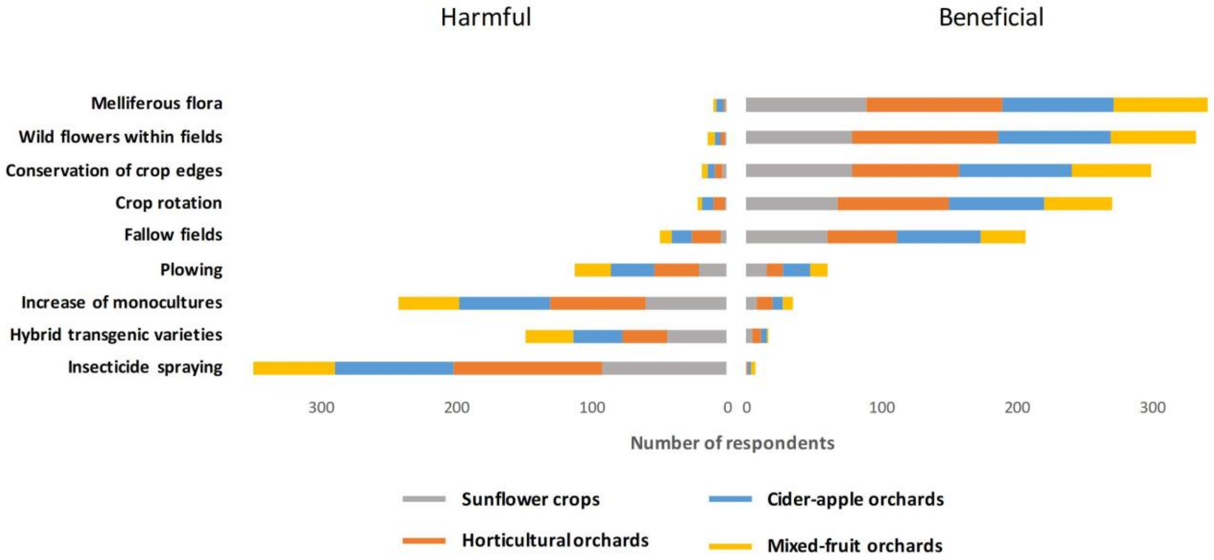
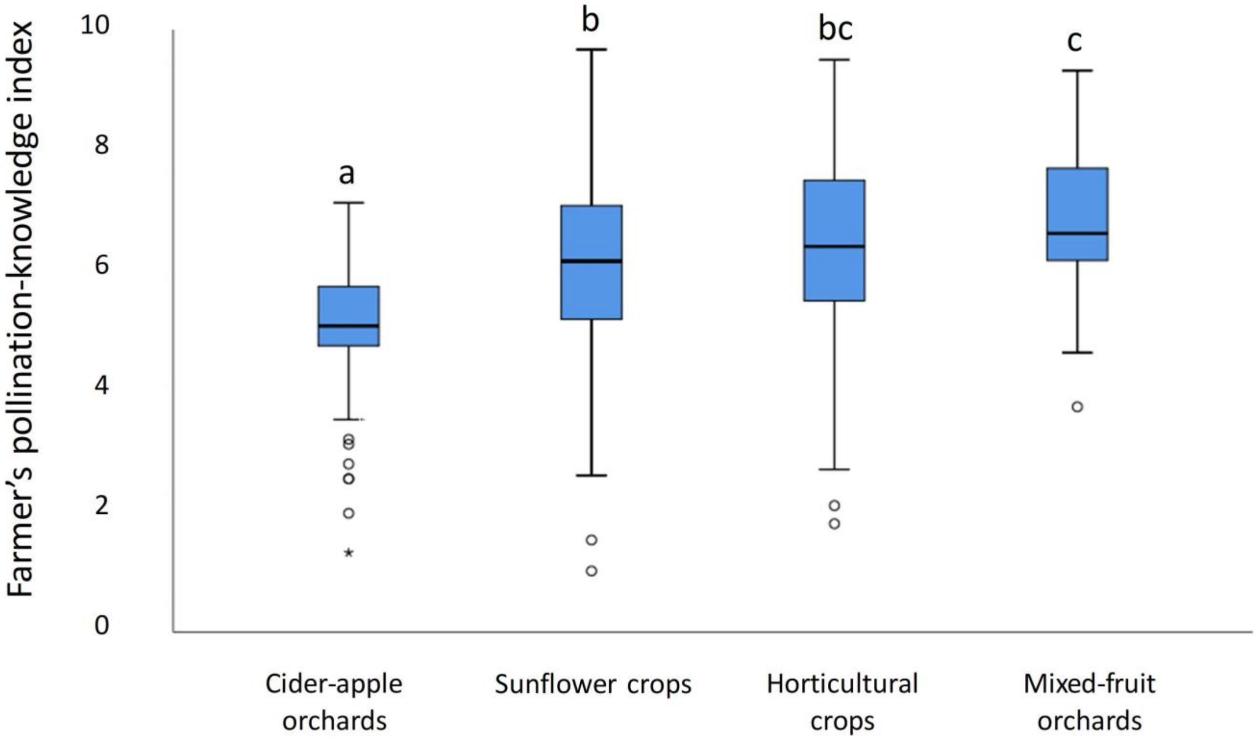
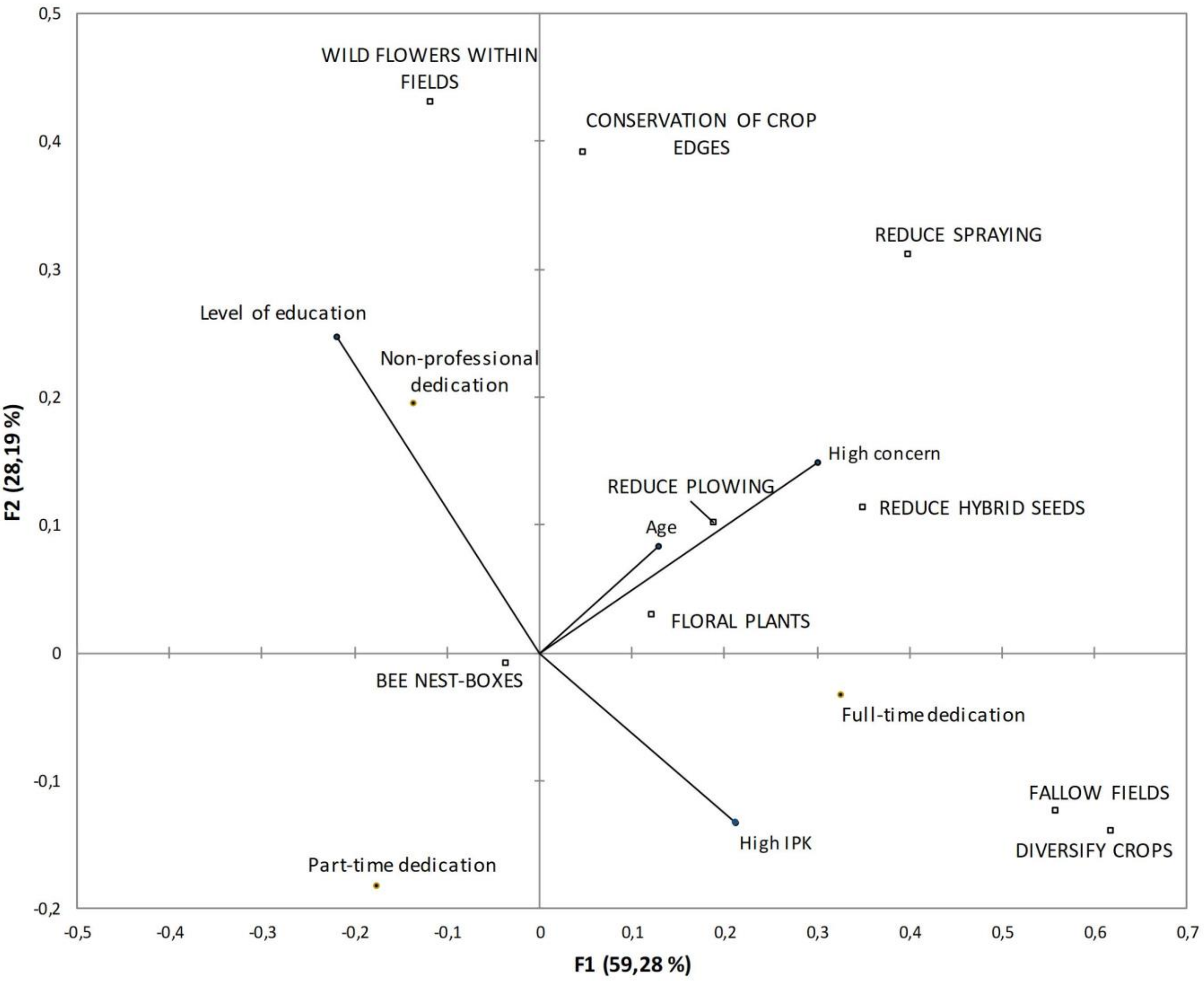

N
A
B
C
D
0 75 150 300 Km
A
B
C
D


A
Beetles
Wasps
Honey bees
Butterflies
Flies
Bumblebees
Other wild bees
Ants
0
1
2
3
4
5
B
Insecticides
Hybrid seeds
Agricultural practices
Predators
Loss of natural habitats
Pests and diseases
Climate change
0
1
2
3
4
Cider-apple orchards
Horticultural crops
Sunflower crops
Mixed-fruit orchards


Harmful
Beneficial
Melliferous flora
Wild flowers within fields
Conservation of crop edges
Crop rotation
Fallow fields
Plowing
Increase of monocultures
Hybrid transgenic varieties
Insecticide spraying
300
200
100
0
0
100
200
300
Number of respondents
Sunflower crops
Cider-apple orchards
Horticultural orchards
Mixed-fruit orchards


Farmer's pollination-knowledge index
10
8
6
4
2
0
a
b
bc
c
Cider-apple orchards
Sunflower crops
Horticultural crops
Mixed-fruit orchards



WILD FLOWERS WITHIN FIELDS
CONSERVATION OF CROP EDGES
REDUCE SPRAYING
Level of education
Non-professional dedication
High concern
REDUCE PLOWING
REDUCE HYBRID SEEDS
Age
FLORAL PLANTS
BEE NEST-BOXES
Full-time dedication
FALLOW FIELDS
DIVERSIFY CROPS
High IPK
Part-time dedication
F2 (28,19 %)
F1 (59,28 %)
0,5
0,4
0,3
0,2
0,1
0
-0,1
-0,2
-0,5
-0,4
-0,3
-0,2
-0,1
0
0,1
0,2
0,3
0,4
0,5
0,6
0,7

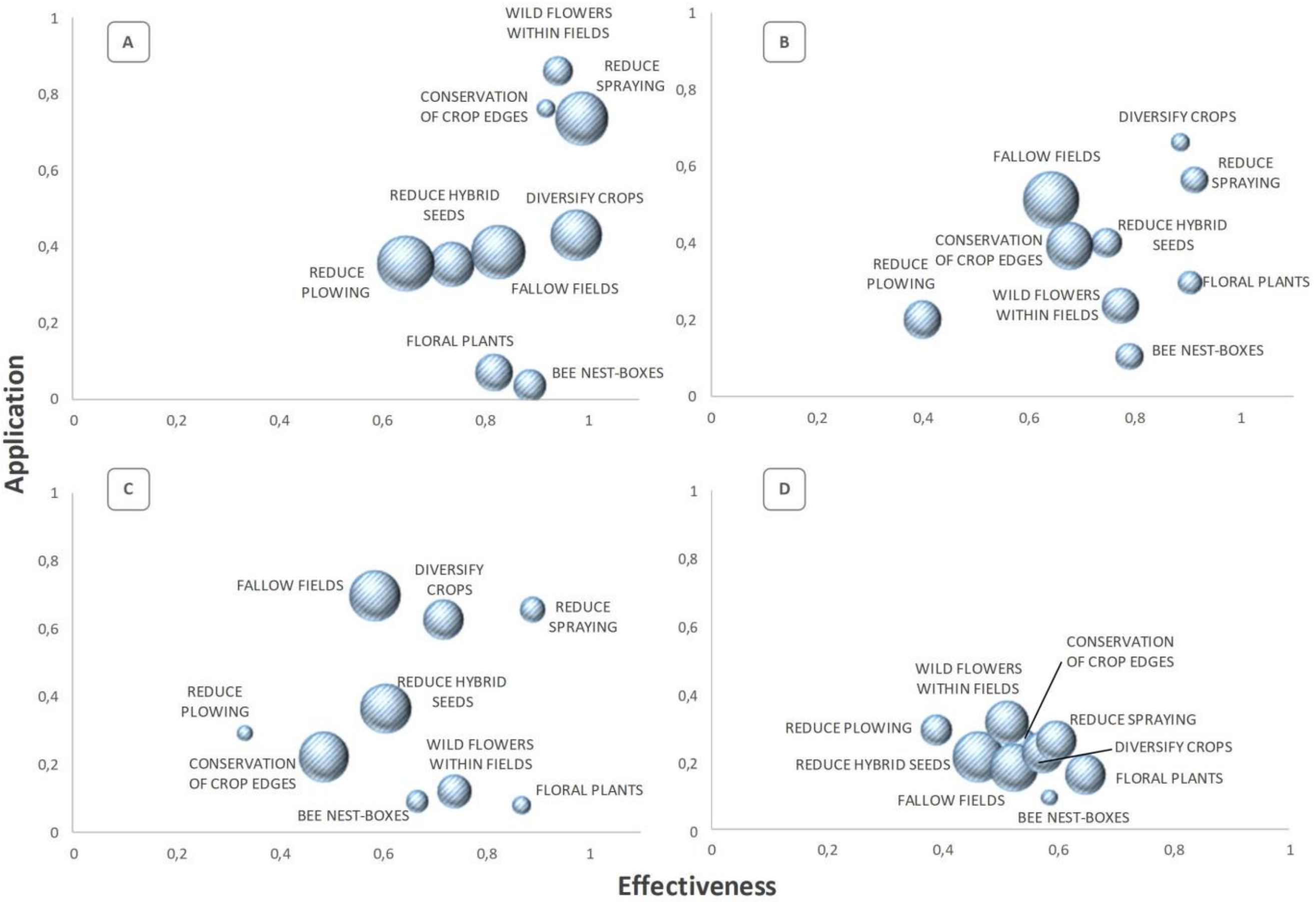

A
WILD FLOWERS WITHIN FIELDS
REDUCE SPRAYING
CONSERVATION OF CROP EDGES
REDUCE HYBRID SEEDS
DIVERSIFY CROPS
REDUCE PLOWING
FALLOW FIELDS
FLORAL PLANTS
BEE NEST-BOXES
B
DIVERSIFY CROPS
FALLOW FIELDS
REDUCE SPRAYING
REDUCE HYBRID SEEDS
CONSERVATION OF CROP EDGES
REDUCE PLOWING
FLORAL PLANTS
WILD FLOWERS WITHIN FIELDS
BEE NEST-BOXES
C
FALLOW FIELDS
DIVERSIFY CROPS
REDUCE SPRAYING
REDUCE PLOWING
REDUCE HYBRID SEEDS
CONSERVATION OF CROP EDGES
WILD FLOWERS WITHIN FIELDS
FLORAL PLANTS
BEE NEST-BOXES
D
CONSERVATION OF CROP EDGES
WILD FLOWERS WITHIN FIELDS
REDUCE PLOWING
REDUCE SPRAYING
DIVERSIFY CROPS
REDUCE HYBRID SEEDS
FLORAL PLANTS
FALLOW FIELDS
BEE NEST-BOXES
Application
Effectiveness
0
0,2
0,4
0,6
0,8
1

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Figure 2

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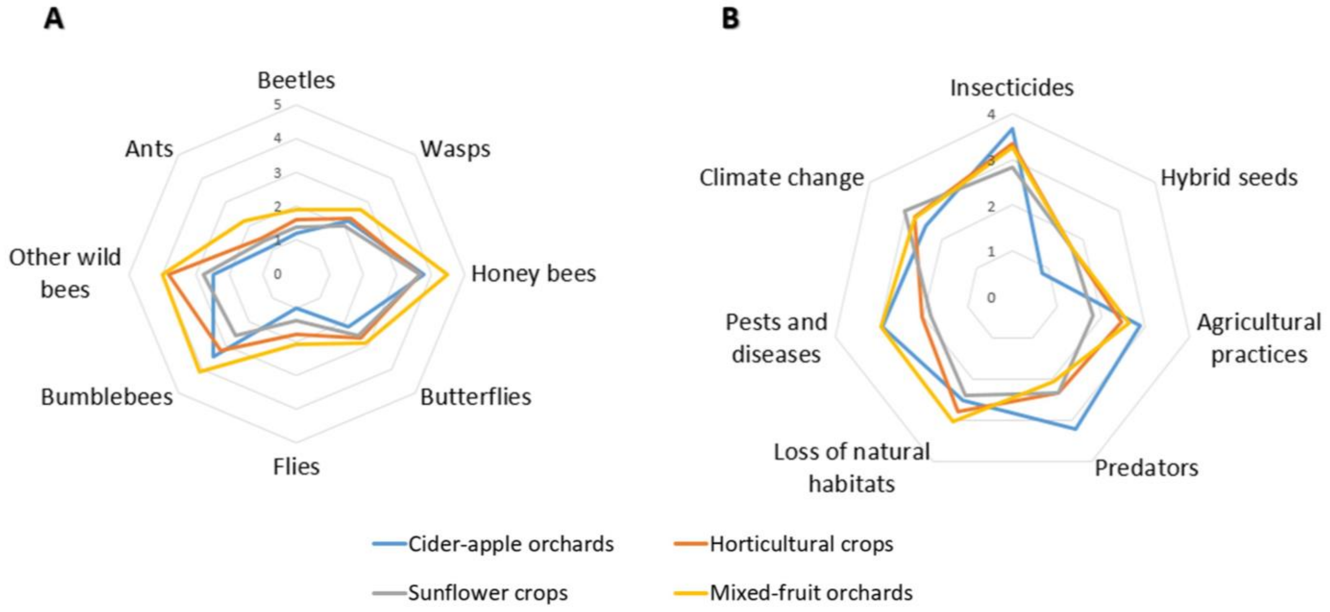

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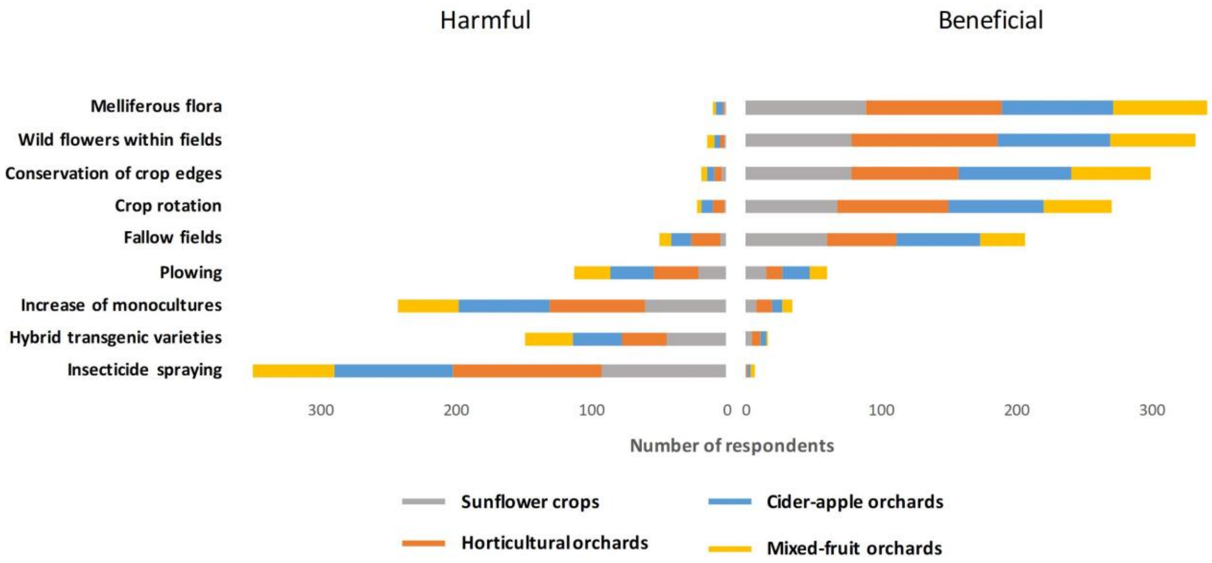

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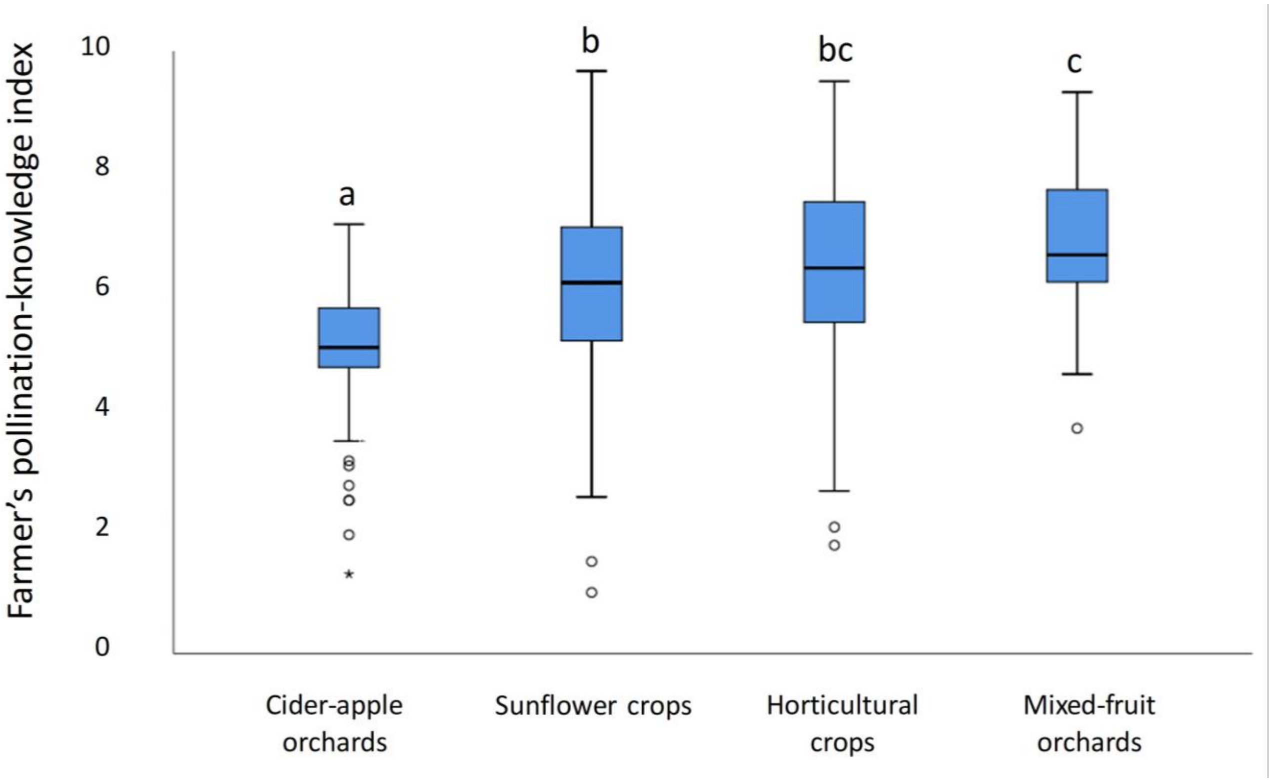

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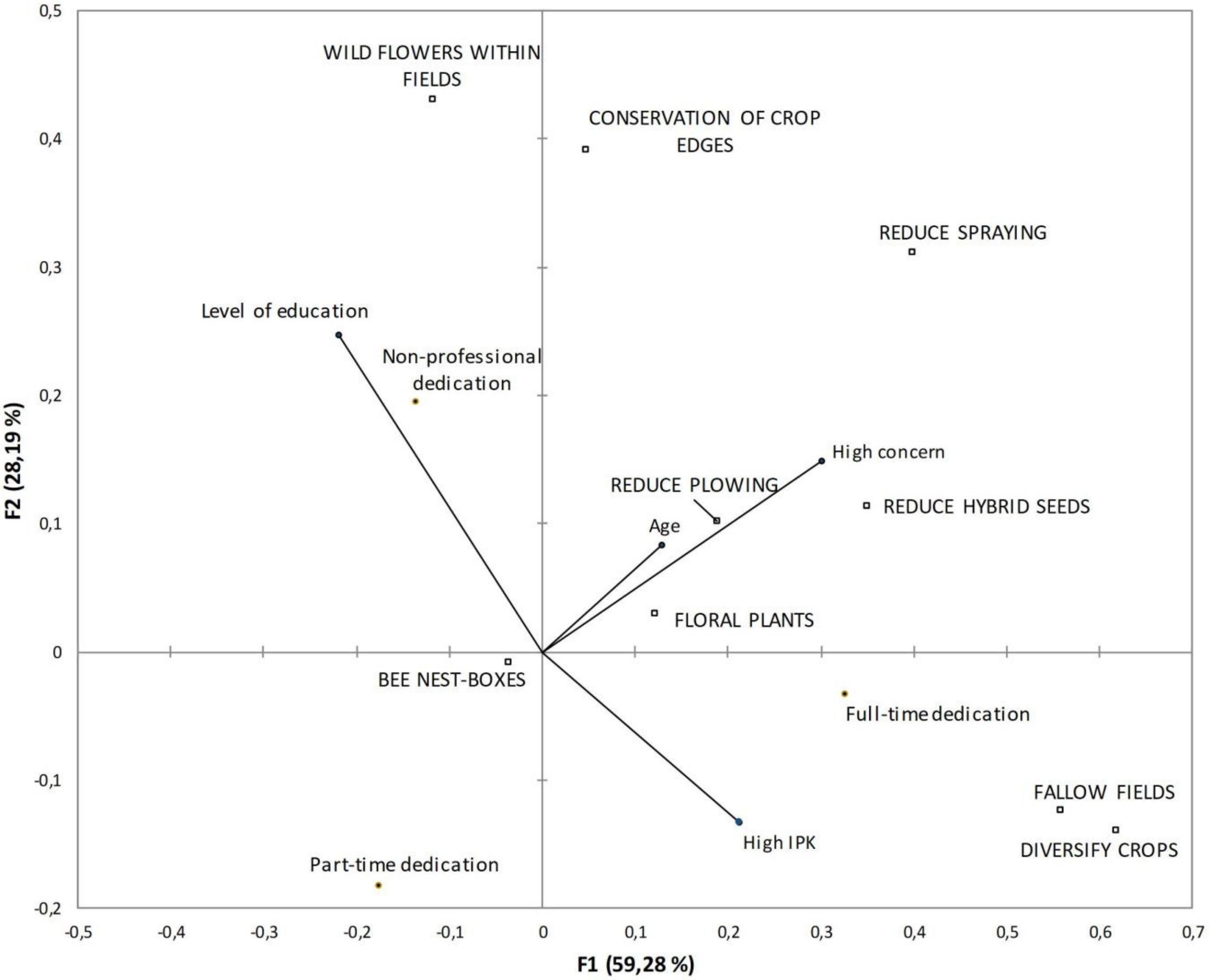

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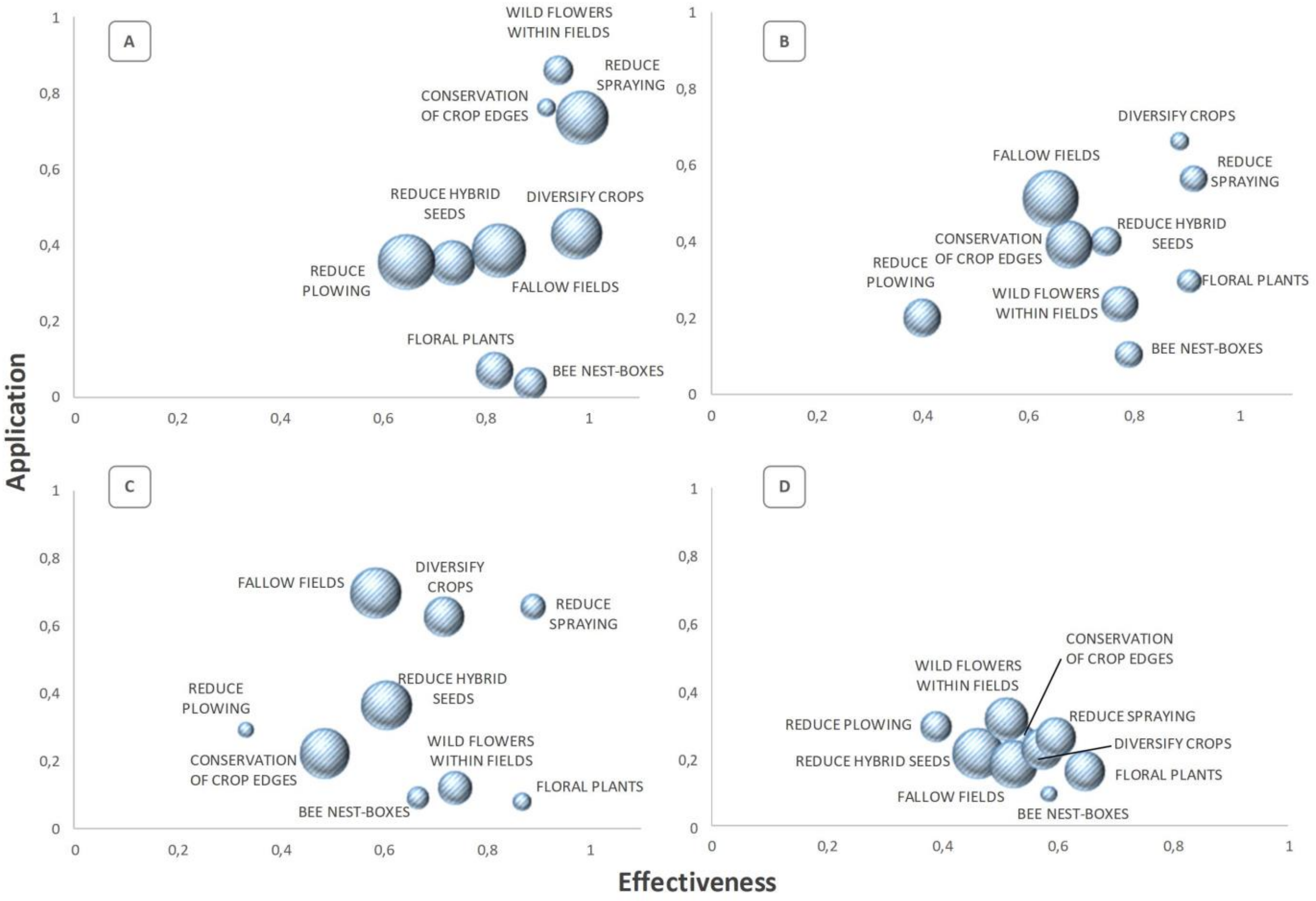
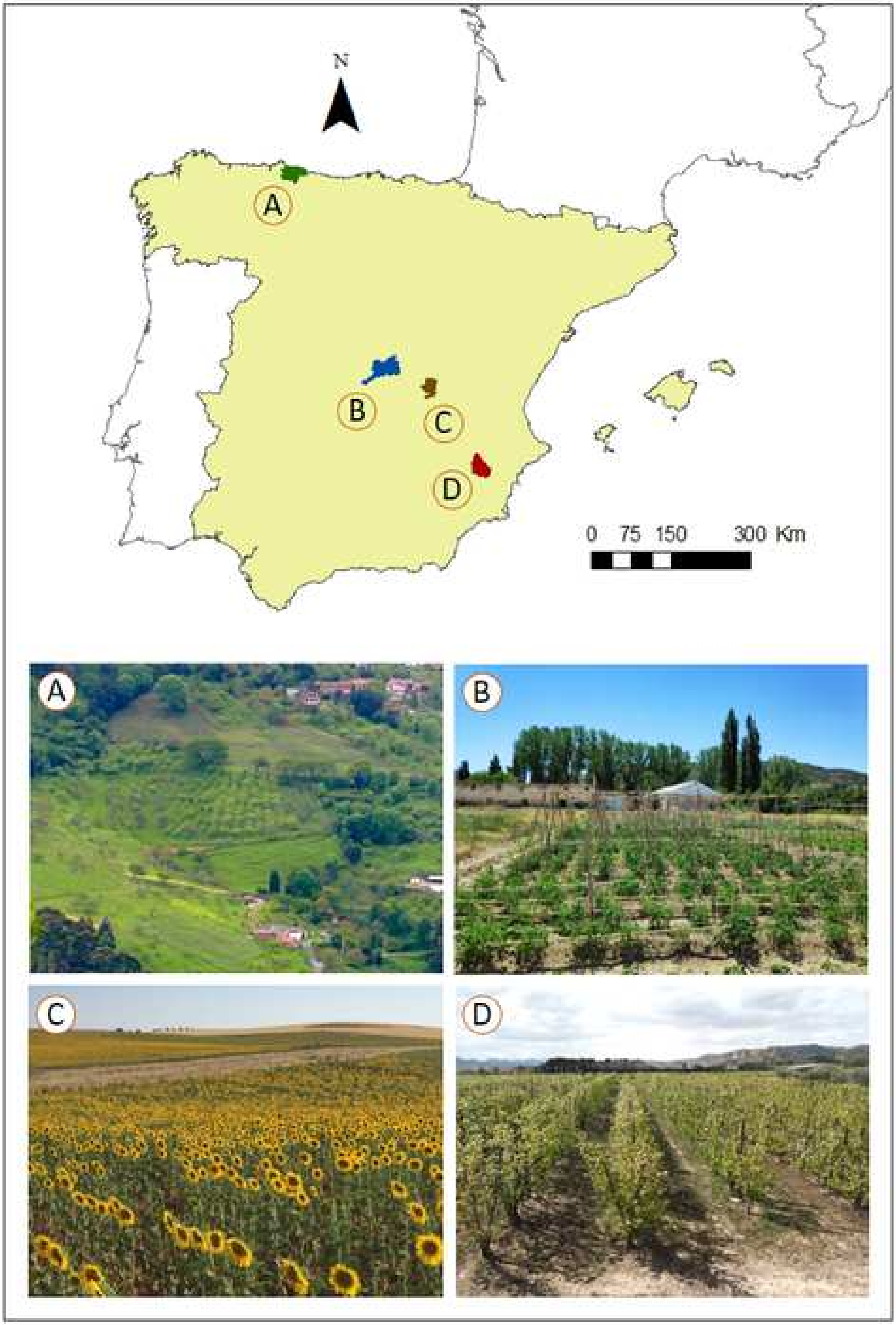


Figure 1



Appendix B. Calculation of the farmers' index of pollination-knowledge (IPK)

The index to estimate farmers' knowledge about the roles of pollinators in their crops was calculated by comparing farmers' responses to four questions of the standardized questionnaire with the responses of two leading experts from each study site (researchers with long experience working with pollination in local crops) to those same questions. According to the experts' criteria, a ponderation factor was later applied when calculating the final score to account for the relative importance assigned to the different questions.

Questions asked and answer categories	**Criteria applied to assign scores**	**Relative contribution to the index**
Do you think that pollinating insects are necessary for food production in this area? (Yes/No)	"Yes" scored 1 point, and "No" scored 0 points.	10%
What type of crops in this area do you think that are more dependent on pollinating insects? (Open answer)	Responses mentioning at least three pollinator-dependent crops that coincide with experts opinion scored 3 points; 2 points were granted to responses mentioning two crops; 1 point for responses mentioning only one pollinator-depending crop; and 0 points for wrong responses.	30%
Which of these (pictures of eight different pollinator taxa are shown to the respondent) are the main pollinators of the crops that you mentioned before? And how much do each of them contribute to crop production (nothing, few, quite a lot, very much?)	Responses were proportionally scored between 0 and 8 points, according to the level of agreement with the experts' opinions on the contribution of each of the different pollinator taxa.	40%
In the absence of pollinators, how much would decrease the production or quality for each crop mentioned above (<25%, 26-50%, 51-75%, >75%)	Answers were scored with 2 points when they fully coincided the experts' criteria; 1 point was granted to respondents that selected the "percentage of production decline" immediately before or after that of the experts; and 0 points when their responses did not match and were far from the expert criteria.	20%

Appendix A. Questionnaire structure and content

A1. Respondent profile about agricultural activities

This section served to obtain information regarding the respondents' activities in each study area, including their relationship with the agricultural sector, the main crops in their farms, and the use of the agricultural products from their farms, among others.

A2. Knowledge of pollinators and their roles

a. Knowledge about the importance of pollinators in production of several crop types.
b. Knowledge regarding the contribution of different types of pollinators (i.e., beetles, wasps, honeybees, butterflies, flies, bumblebees, other wild bees, and ants) to the predominant crops in each study site. For this section, we showed respondents a plate with pictures of each pollinator type, with the objective of evaluating the respondents' knowledge of the contributions of different pollinator taxa to crop production.

A3. Perception of drivers of change affecting pollinators

a. Perception of the current status of pollinator insects in each study site.

b. Farmers' degree of concern about pollinators.

c. Perception of the degree of importance of different potential causes of pollinator decline: insecticides, hybrid seeds (coated with systemic insecticides), agricultural practices, invasive predators, loss of natural habitats, pests and diseases (i.e., parasitic *Varroa* mites, viruses), and climate change.

d. Perception about the beneficial or harmful effects of different agricultural practices: presence of wild-flowers within fields, use of hybrid transgenic varieties, increase of monocultures, conservation of crop edges, herbicide spraying, presence of fallow fields, crop rotation, pesticide spraying, presence of melliferous flora, and plowing.

A4. Attitudes toward adoption of pollinator-friendly practices

a. Current adoption of several practices to promote the presence of pollinators: installing bee nest-boxes, reducing spraying, reducing the use of hybrid seeds (i.e., hybrid seeds coated with systemic insecticides), conserving crop edges (i.e., strips of herbaceous plants, hedgerows or bushes, between adjacent fields), installing floral plants within the farmers' fields, reducing plowing, maintaining wild flowers within fields, increasing the number of fallow fields, and diversifying crops.

b. Perception on the effectiveness of each of the previously mentioned practices.

c. Willingness to adopt those effective practices in the future.

A5. Socio-demographic information

Socio-cultural and demographic variables included age, gender, level of education, employment, and place of residence.