The role of landscape structure on the pollination service of *Apis mellifera*

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**Abstract**

*Apis mellifera* is the worldwide most important pollinator of crops, and a keystone species for most of the angiosperms (flowering plants) which constitute our feeding, making it crucial to our health and survival. The composition and configuration of the landscape in which *Apis mellifera* lives will likely determine its well being and the pollination service it can provide to the crops. Here we built a spatially explicit model which predicts the spatial distribution of visits to crop of *Apis mellifera* by simulating each day the trips of honey bees in the crops, the demographical dynamic of each hive, and their honey production. This model goes beyond existing approaches by including 1) a flower resource affected by the nectar and pollen extraction by the pollinators, 2) a pollinator growth dynamic which allows competition through short term resource depletion, 3) a probabilistic approach of the foraging behavior, modeling the fact that the pollinator has only a partial knowledge of the resource on its surroundings, and 4) the unique foraging habits of *Apis mellifera* regarding its election of foraging sites. With this simple but quite realistic model we show the importance of keeping a minimal fraction of natural habitat in an agricultural landscape. We also evaluate the effects of the landscape structure on the pollination, and demonstrate that it exists an optimal size of natural habitat patches which maximize the pollination service for a fixed fraction of natural habitat. Finally, we reveal the effect of the distinct ways of mixing culture on the number of visits to the crop.

**Keywords:** pollination, *Apis mellifera*, competition, landscape structure, ecological intensification

1. **Introduction**

The intensive agricultural production systems developed during the twentieth century are facing multiple crises, mostly due to the degradation of the natural ecosystems they provoke [1–3]. One of these crisis is the fast decline of the pollinators populations, and consequently a decrease in the pollination service quality [4, 5]. Pollinators are not only essential for the good functioning of most of the terrestrial ecosystems, but they are also fundamental to our survival [6, 7]. They are keystone species for many ecosystems, allowing the sexual reproduction of a great part of the flowering plants which constitute the basis of human alimentation [6]. Even though for some plants pollination can also be performed by wind or water, analogous pollination is more efficient through the intervention of animals, mostly insects, leading to better genetic diversification and all the benefits which come with it [8, 9]. For some plants, fruit trees for example, pollination is also the only option for sexual reproduction [10]. Among all the pollinators, bees are certainly the most important [4–6, 11]. Even if recent studies demonstrate the importance of wild bees, the managed bee *Apis mellifera* holds a particularly important place in the pollination service [12, 13].

In this context, the reduction of floral diversity requested by intensive monoculture particularly endangers wild pollinators, but also weakens managed species [4–6, 11]. Countermeasures to this are constantly being developed to reach a better agriculture, productive, sustainable and healthy for the consumer [7, 14, 15]. These include the structuring of landscapes to improve the ecological services provided by the biological actors of the crop’s growth and reproduction, such as pollinators [7]. The experimental approach to study the effect of the landscape structure on pollination quickly reaches limits in term of quantity of available experimental farms and of reproducibility of experiments. An approach in terms of mathematical modelling is particularly fit in such cases, since it allows the fast exploration of a variety of scenarios.

Many models have been developed in order to under-
stand the needs and implications of sustainable pollination. Some of these models usually consider an homogeneous environment and two interacting populations (plant and pollinator) \cite{16,17}. They generally do not include the spatial dimension, ignoring the effect of spatial plant distribution or the distance between plants and pollinators' nests. Nevertheless, such models have allowed to understand many characteristics of the plant pollinator interactions, in terms of the impact of the presence of semi-natural habitat \cite{16}, or the coevolutionary dynamics between plant and pollinator \cite{17}. Still, they are not fit to study the effect of landscape configurations. Other models are spatially explicit, even incorporating a temporal dimension with plant and pollinator seasonality or dynamic. They are able to predict the probable distribution of the pollinators on a large scale according to the resource distribution \cite{18,19}. They can also infer the impact of some forms of managements or treatments of a particular landscape on pollination \cite{20}. However, they do not acknowledge competition making the assumption that there is no floral depletion \cite{18–21}. Some make the assumption that pollinators forage on the closest sites to the nests \cite{18}, and other that they forage on the sites of highest flower resource \cite{19,20}, assuming that the pollinators do not know anything about their environments, or else have a perfect knowledge of it. We suspect that these assumptions generate either an overestimation or an underestimation of the visits to low resource patches, and it is one of the issues we pretend to assess in the present work.

The model proposed here integrates space, temporal dynamic and seasonality to infer the spatial distribution of visits to flowers, from a given map of land cover compatible with a Geographic Information System (GIS). It considers only managed hives of \textit{A. mellifera} whose well being only depends on the available resource on their surroundings. To our knowledge, it is the first process-based model of crop pollination to include: 1) a flower resource dynamics which depends on the pollinator foraging behavior, 2) a pollinator growth dynamics which allows competition mediated by the depletion of the resource, 3) a probabilistic approach to foraging behavior, modeling the fact that pollinators have partial knowledge of the resource on their surroundings, and thus do not always forage on the site of better flower resource, and 4) the unique foraging habits of \textit{A. mellifera} regarding its election of foraging sites. As a first stage, we do not consider the effects of diseases, pesticides, or natural catastrophes. We chose to model only managed hives because bee-keeping is a worldwide spread practice and the results we can produce will be applicable to more landscapes. In order to isolate the effects of the landscape structure we also compare the results obtained with the spatially explicit model to a similar mean field model that assumes a uniform distribution of the different types of land covers.

The landscape configurations that we can observe in agricultural exploitation around the world has been mostly developed based on the experience of the growers, and are usually designed to increase the size of the cultivated area \cite{22}. The treatments and managements tested on the field or \textit{in silico} to improve the pollination service usually intend to modify the fields by adding semi-natural habitat such as flower strips or grassy bands, mostly on the margins of the crops \cite{20,23,24}. But little is known about the global effects of spatial arrangements of habitat in agricultural system \cite{25}. In this work we study the basis of the agricultural landscape designing. We try to built a theoretical foundation for studying the effect of general compositional and structural features of the landscapes, such as the fraction of natural habitat, size of patches, and meshing of the patches of different cultures on artificial maps, in order to be able to design new fields which optimize the pollination by \textit{A. mellifera}.

2. The spatially explicit model

The impact of the fraction of natural habitat on ecological services has been broadly studied with mathematical models \cite{16–21} and analyzed by considering, at different levels of description, a mean field model. While some of these works analyze heterogenous landscapes, their detailed topology is screened by the coarse graining characteristic of mean field considerations. In the present work we want to go beyond such description, evaluating not only the effects of the averaged value of this fraction but also the impact of the spatial distribution of natural habitat on the pollination service by \textit{A. mellifera}. Managed hives are usually placed at the interface between the crop and the natural habitat in order to achieve an equilibrium between the need of resources for the bees and the need of crop pollination for the grower \cite{26}. One of our hypotheses is that the size of this interface is a key factor for the pollination service, i.e. not only the fraction of natural habitat but also the shape adopted by this fraction are relevant. The agreements and differences between the present model and a mean field one will be shown in Section 4.

2.1. Landscape maps and resource dynamic

The maps used by the model are grids readable by GIS software, composed of a discrete number of habitat categories. Each habitat has a resource carrying capacity, a daily resource renewal coefficient and a blooming period. The value of the resource is equal to its carrying capacity during the blooming period, and equal to zero the rest of the year. Each time the resource is consumed by the bees, it is linearly renewed up to its carrying capacity.

We created random maps of 3 km by 3 km, with each cell measuring 10 m by 10 m. This scale is fine enough to draw realistic maps relevant to the size of \textit{A. mellifera} foraging sites (around 30 m by 30 m), and it is large enough to be interesting regarding their flight range (around 1 km), such that not all hives can forage on the entire map. Maps are composed of two habitats: a natural one whose blooming period is all spring and summer, and a monoculture...
with a 35 days blooming period. We used maps with different fractions of natural habitat and various values of edge density (number of cells of a given habitat which are at the border, divided by the total number of cells of the habitat). To build them, we used an algorithm of nucleation in 2D [27], varying the number of patches of natural habitat and the number of nuclei from which it grows. More nuclei means smaller and more dispersed patches, and thus a higher edge density. The value of the resource is the same in the natural habitat and in the cultivated crop, so that the bees do not have any preference when the flowering periods overlap.

2.2. The hives

Each hive is characterized by its position on the map, its population of bees and its quantity of honey. When the population of a hive falls below a threshold, the hive is considered dead and removed from the list of hives.

To include seasonal environmental change we formulate the model in two periods. During spring and summer, bees forage nectar and pollen and produce honey and new bees. In autumn and winter they enter in dormancy and stop their foraging activities [28].

Spring and summer

We consider that, during spring and summer, the number of bees in a hive obeys a logistic dynamic whose carrying capacity depends on the amount of stored honey. In turn, honey is produced from the nectar and pollen harvested by the foragers. Its production is limited by the amount of nectar harvested by foragers and by the number of bees which can store the honey. Honey is also consumed proportionally to the number of bees. With these assumptions, we propose the following discrete dynamics for each hive, with each time step corresponding to one day:

\[ B_{t+1} = r B_t \left(1 - \frac{B_t}{H_t} \right), \]
\[ H_{t+1} = H_t - c_s B_t + \alpha \frac{B_t G_t}{\beta G_t + B_t}, \]

where \( B_t \) and \( H_t \) are, respectively, the number of bees and the amount of stored honey of the hive at time \( t \). The parameters that determine the evolution of these two variables are \( r \), the growth rate of the hive in spring and summer, \( \lambda \), the carrying capacity of bees per gram of honey, and \( c_s \), the daily consumption of honey per bee during the warm season.

Observe that the production of honey depends both on \( B_t \) and a third variable, \( G_t \), which is the gain of nectar and pollen on day \( t \). This algebraic dependence on both variables ensures that the production grows proportionally to both of them at low values, and saturates when either is much larger than the other. The parameter \( \alpha \) represents the conversion factor between the quantity of nectar and pollen brought back to the nest and the honey produced, and \( \beta \) the conversion saturation constant per gram of nectar and pollen. During spring and summer this gain of pollen and nectar depends on the spatial distribution of the resource and the presence of competing hives. In the following we discuss its dynamic in more detail.

**Apis mellifera** is faithful to their harvesting sites: when they choose a site, they forage on it all day sending a great number of bees, sometimes until the resource of nectar and pollen is completely drained [29]. In the model, each day a hive chooses a number of foraging sites with a size of 30 m by 30 m (9 cells), where it will send a fraction of foragers to harvest. The daily gain of the hive is the sum of the gains that each “squad” of foragers could obtain from the foraged site:

\[ G_t = \sum_{i=1}^{M(B_t)} g_{i,t}(x,y), \]

where \( M \) is the number of squads which can forage from a hive of size \( B_t \) (i.e., an integral fraction of the number of bees \( B_t \)), and \( g_{i,t}(x,y) \) is the local gain of squad \( i \) at the foraging site centered at \( (x,y) \).

**Apis mellifera** choses their harvesting sites at the beginning of each day relying on relevant information provided by the scouts [30]: the resource at the sites and their distance from the nest. In the model, we implement this by choosing harvesting sites at random, at the beginning of each day, according to a specific distribution probability as follows. The probability to chose site \((x,y)\) is defined as depending on \( R_t(x,y) \), which is the total resource in the 9-cells Moore neighborhood centered at \((x,y)\), and the flight cost to reach them, \( f(d) \):

\[ P(x,y) = \begin{cases} \frac{(R_t(x,y)f(d))^\alpha}{\sum_{(u,v)\in\mathcal{R}_f}(R_t(u,v)f(d))^{\alpha}}, & \text{if } d < r_f, \\ 0, & \text{otherwise,} \end{cases} \]

where \( d \) is the Euclidean distance from the hive to \((x,y)\) and \( r_f \) is the range of flight of the bees. The cost \( f \), normalized to the interval \([0,1]\), is an affine decreasing function of \( d \), with \( f(0) = 1 \) and \( f(r_f) = 0 \). The exponent \( \alpha \) represents the knowledge that the hive has of the resource on its surroundings; if \( \alpha = 0 \), the hive chooses its foraging sites uniformly at random, and when \( \alpha \to \infty \), the hive systematically chooses the site with the highest harvestable resource. In our studies we used \( \alpha = 3 \), which gives a realistic behavior for the scouts.

Once the harvesting sites are chosen, the hive sends a fraction \( \nu_i \) of foragers to each site \( i \), also depending on resource and distance. This parameter \( \nu_i \) is a ponderation factor so that the more harvestable resource there is on a site, more bees are sent to it:

\[ \nu_i = \frac{R_t(x,y)f(d)}{\sum_{\text{chosen } (x,y)} R_t(x,y)f(d)}. \]

As a result of this election process, several hives can choose the same sites and thus compete for the resource.
Note that the probability for hives to choose the same site is higher when the resource is globally low on their surroundings, and thus the competition is higher.

We implement this possibility of hive competition by sorting each day a random harvesting order $\tau$ for each hive. Sorting this order every time step averages the effect of the chosen order. Let $R_{\tau}^i(x,y)$ correspond to the value of the resource after the turn of the hive which feeds at round $\tau$. The actual harvestable resource for the next hive at the site is the product of $R_{\tau}^i(x,y)$ and $f(d)$. If the resource is in excess, the bees sent to the site harvest the maximum value they can carry during the day, $f(d)\nu_k B^i_\tau$, but if the resource is lower than this value, they take it all. The daily local gain of hive $i$ at site $(x,y)$ can then be described as follows:

$$g_{i,t}(x,y) = \max(f(d)\nu_k B_\tau^i, R_{\tau}^i(x,y)).$$

(5)

In the results we will also discuss the total number of visits, which is a proxy for the pollination efficiency. The number of visits to a site on one day is the sum of the visits made by all the visiting hives. In turn, the visits made by each of these hives is the product of the number of bees that flew to the site, the average number of trips made by one bee, and the average number of flowers visited in one trip. Appropriate values are used for these parameters to compute the pollination service, as will be discussed below.

**Autumn and winter**

The studied subspecies of *A. mellifera* is domestic. At the end of each summer, honey is collected by a beekeeper and replaced by syrup [31]. The amount of syrup provided to each hive is the same, and has been set to be equivalent to 30 kg of honey in the following simulations.

During autumn and winter, bees enter in dormancy and they do not forage anymore. They stay in the nest feeding from the syrup. To maintain the inner temperature within a comfortable range, they aggregate to form a ball called a winter cluster. The heating capacity of this structure depends on its size [28], so the mortality diminishes with the radius of the ball, which is proportional to the cubic root of the number of bees. Mortality also diminishes with the quantity of syrup available in the hive. When a hive is too small it does not overcome the winter because of the mortality induced by their incapacity to maintain the warmth of the hive. Also, when the bee population of a hive is too large for the amount of stored syrup, mortality also increases due to starving [28]. Within this scenario, bees and syrup dynamics during winter can be described by the following equations:

$$B_{t+1} = B_t - \mu_w B_t^{-1/3} \frac{B_t}{S_R + S_t},$$

(6a)

$$S_{t+1} = S_t - c_w B_t,$$

(6b)

1We calibrated the value of the resource so that one unit of resource corresponds to the maximum carried by a bee in a day. Alternatively, an additional parameter in this expression could take account of the average number of flowers visited by a bee.

where $S_t$ is the amount of syrup at time $t$, $\mu_w$ is the mortality rate during winter and $c_w$ is the consumption of honey per bee per day during winter. Observe that $\mu_w/S_R$ is the mortality rate when there is no syrup left in the nest.

2.3. Setting the parameters

Since our main interest is the impact of landscape structure on pollination, all the parameters which concern the hives dynamic have been kept constant in the simulations (both in the spatially explicit model and in the mean field presented below).

Some of these parameters have been estimated from real data, such as the number of elected sites and the number of trips per bee per day, and have been set in the range of observed values. All the other parameters have been set such that the results fit into a biologically relevant range of values for the number of bees and the production of honey.
are well mixed, diluting the resource of the natural habitat edge density means that the natural habitat and the crop are unreachable for the bees. On the contrary, a large are well segregated, making some points at the center of the natural habitat. The maximum of the number of visits shifts towards low edge density for late blooming period, the natural habitat. The maximum of the number of visits and the honey production on each map at the end of the blooming period of the newly introduced crop is earlier than the first one. We also observe that the number of visits is larger when the two crops are in proportions such that the latest blooming crop is in a bit higher quantity than the earliest one, and when the two crops are well segregated. Indeed, mixing the crops decreases the density of the resource of a single crop at its blooming period. But because their blooming periods do not overlap, the crops do not compete for pollinators.

3. Results

One of the relevant questions about the role of landscape structure in the system under study is how the hives are affected by the competition and the resource available on their neighborhood. To assess this question we placed hives in different situations, in large or small natural habitat and with or without competition. The results are summarized in Fig. 1. We can see that, in the absence of competition (full lines), having a large or small natural habitat at disposition does not influence much the hive dynamic as long as the natural habitat is large enough to sustain a single hive. But when there are more hives (dotted lines), the effect of competition is higher in a small natural habitat (red hive), than in a large one (black hive).

Note also that the number of bees of a hive is generally steady each year, but if the resource is very low and the competition very high, the number of bees declines until the hive dies. This result is quite similar to what is found in other models of study of *A. mellifera* [32].

To quantify the effect of the amount of natural habitat we performed extensive simulations, monitoring the foraging activity of the bees on one thousand random maps during 4 years. For each map, we placed 100 nests at random on the borders of the natural habitat. The number of visits and the honey production on each map at the end of summer are shown in Fig. 2.

The number of visits reaches a maximum which shifts toward large fractions of natural habitat for late blooming periods, from around 9% for early spring to 20% for late summer (remarkably, a similar result is obtained with the mean field model presented below). We can also see that there is an additional dependence on the edge density of the natural habitat. The maximum of the number of visits shifts towards low edge density for late blooming period, from 0.6 for early spring to 0.2 for late summer. A low edge density means that the natural habitat and the crop are well segregated, making some points at the center of the crop unreachable for the bees. On the contrary, a large edge density means that the natural habitat and the crop are well mixed, diluting the resource of the natural habitat out of the blooming period. For the number of visits to be maximal, the patches of natural habitat can not be too dispersed, but can not be too segregated either.

Then, we tried to investigate the influence of the crop structure on the number of visits, more precisely when the crop is constituted of two types of cultures with distinct flowering periods. We took the map which gave the largest number of visits for an intermediate blooming period (late spring-early summer), and we introduced a new crop into the field, with a flowering period of the same duration but before or after the blooming period of the first one. We generated maps with different values for the fraction of crop 1 (flowering period from 80 to 115), and for the edge density of crop 1, which is calculated as the number of cells of the grid at the interface between crop 1 and crop 2 divided by the area of crop 1. For each map we placed again 100 nests at random on the borders of the natural habitat. The number of visit on each map at the end of summer are shown in Fig. 3.

We can see that introducing a new type of crop does not always increases the number of visits, in particular when the blooming period of the newly introduced crop is earlier than the first one. We also observe that the number of visits is larger when the two crops are in proportions such that the latest blooming crop is in a bit higher quantity than the earliest one, and when the two crops are well segregated. Indeed, mixing the crops decreases the density of the resource of a single crop at its blooming period. But because their blooming periods do not overlap, the crops do not compete for pollinators.

4. Mean field model

Let us now describe a mean field model of the system, which assumes a uniform distribution of the different types of land covers.

The dynamic of the hives during autumn and winter is the same as in the spatially explicit model: bees stop their foraging activities to enter in dormancy during autumn and winter (Eqs. (6)).
We assume that during the blooming period the natural habitat is flowering during all spring and summer. When the fraction of natural habitat is small, a small increment of its value induces a proportional increase of the harvest. But when this fraction is high, the gain does not increase as much with the addition of natural habitat because it is limited by the foraging capacity of the bees. Let us say that $x$ represents the fraction of natural habitat within the flight range of the hive and $k_s$ is the saturation constant of the nectar and pollen harvest. The gain is:

$$G_t = \begin{cases} R_{max}B_t p, & \text{during the crop blooming period,} \\ R_{bas}B_t p, & \text{otherwise,} \end{cases}$$

where

$$R_{bas} = R_{max} \frac{x(1 + k_s)}{x + k_s},$$

and $p$ is the proportion of pollinators in the hive.

The number of visits from the hive to the crop each day is proportional to the number of foragers and to the fraction of monoculture:

$$V_t = (1 - x)B_s p,$$

where $(1 - x)$ represents the fraction of crop within the flight range of the hive.

Results of the mean field model

As mentioned before, a mean field model is suitable to estimate the influence of the fraction of natural habitat on the pollination service by *A. mellifera* without considering the effect of the distribution and shape adopted by this fraction. Here we present a mean field model that captures the relevant features included in the spatially extended one. We made simulations for different values of the fraction of natural habitat, and measured the number of visits of a hive during a 4 years period. The results are shown in Fig. 3.

We can see that the production of honey increases with the fraction of natural habitat, saturating for large values of it. We can also see that the honey production barely depends on the blooming period of the monoculture. The number of visits, instead, strongly depends on the blooming period. It has a maximum for a fraction of natural habitat which ranges from 11.6% for an early blooming to 28.1% for a late one. The numbers of visits on late blooming crops are larger because the honey bee population is also larger during this time of the year.

5. Discussion

The spatially explicit model presented in this article provides a valuable insight about the impact of the landscape structure on the pollination service. We have seen...
It is remarkable that some published experimental results show that a mean field approach accurately predicts the impact of the fraction of natural habitat on the number of visits. Nevertheless, it fails to explain much of the richness of the possible outcomes since the disposition of the natural habitat patches and the competition between hives showed to have an influence on the pollination service. Regarding the natural habitat, the model shows that a minimum amount of natural habitat is necessary in order to optimize the pollination service, but the spatial organization of the habitats deserves attention as well. The size of the natural habitat patches needs to be large enough in order to provide high density resources, but small and dispersed enough in order to allow the bees to visit all the field. The model also shows that mixing crops of different blooming periods allows to increase the total number of visits and, accordingly, the yield. However, mixing them too much decreases the density of each crop during its blooming period and then diminishes the number of visits. It is remarkable that some published experimental results suggest a maximum of pollination around the same values of edge density and fraction of natural habitat as the ones found by means of our model (20% of semi-natural habitat for an edge density between 0.3 and 0.4) [25].

Our results apply to hives which are managed at low cost, with a single introduction of syrup before winter. In some places, with a particular lack of natural habitat offering flower diversity, agreements are made between farmers and beekeepers in order to keep alive enough hives for pollination purposes [33]. They can be moved across the fields through the seasons, and regularly supplied with syrup if needed. A good beekeeper can effectively erase the effect of landscape structure, but at a great cost in time and money.

In our analysis we have presented the total number of visits over the map as one of the important outputs, which is different from the economically more relevant fruit production. It is known that generally around ten visits per flower are enough for the fecundation to occur, and that more visits not only do not improve production, but can even damage the pistil of the flower and lower fecundation probability [29, 34]. We have also calculated production from the local number of visits each day, but because hives have identical foraging behaviour, fruit production and number of visits are similar. Consequently we did not find it useful to show these results here. However, we can say that the slight differences observed between visits and production only occur when the competition is strong and the flowers are overvisited. These differences are likely to increase for a larger number of hives. A detailed analysis will be presented elsewhere.

In order to make a coherent comparison, the number of hives has been kept constant in all the landscapes studied. But the pollination service does not grow linearly with the number of hives. Each landscape has a hive carrying capacity, beyond which the pollination service does not improve, and can even decrease due to competition-induced hive mortality (see Fig. 5). These non-linear effects between the number of hives and the pollination efficiency detected by the model have also been described in several field reports [29].

It is important to raise a word of caution about out results concerning the impact of the fraction of natural habitat on production. What we demonstrated is that there is a minimum fraction of natural habitat needed in order to maintain a sufficient population of *A. mellifera* to pollinate the field. But it does not mean that increasing the fraction of natural habitat in an agricultural landscape will necessarily diminish the production. Indeed, a natural habitat such as a forest not only serves as a nectar and pollen supply for *A. mellifera* all over spring and summer, but also provides several other ecological services, as a wind breaker, air cooler, providing water retention and shelter for wild pollinator [35], etc. The minimal fraction of natural habitat which begins to damage the pollination service by *A. mellifera* is likely to be lower than the one which will damage the actual yield of crop.

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**Figure 4**: Analysis of the impact of the fraction of natural habitat on the honey production and the annual number of visits with the mean field model. Top: Mean annual production of honey as a function of the fraction of natural habitat. Bottom: Annual number of visits to the crop as a function of the fraction of natural habitat. The colors correspond to different blooming periods, as shown in the legend in days. Day 0 corresponds to the first day of spring.
It is generally acknowledged that, while *A. mellifera* is the most used pollinator of crops, they are not the most efficient [12, 29] ones. A model of pollination by wild bees using the same resource maps has already been developed by us, and will be used to characterize the effects of the landscape structure on the pollination by native pollinators on artificial and real landscapes, as well as the impact of mixing native and managed bees on pollination.

The goal reached by this work is a characterization of the effect of some structural features of landscapes on the pollination service. The model has been developed to analyze the pollination service in real GIS maps with a larger number of land covers and it is also able to predict the impact of slight changes in real landscape composition and configuration on the pollination service. It will be used in a subsequent study to predict the pollination service on different real agricultural landscapes. We hope that it can become a useful tool for farmers, beekeeper and policymakers in order to understand the impact of the composition and configuration of the agricultural landscape on the pollination service by the honey bee, help them to design their farms and contribute to a the sustainable use of the environment.

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