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Using the Lonsdorf and ESTIMAP models for large-scale pollination mapping (Case study: Iran)

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Abstract

The Lonsdorf model simply considers the potential of land covers in providing nesting habitat and floral resources for mapping pollination services in different landscapes. However, this model does not take into account topographic and climatic factors in its modeling and does not include edge effects of factors such as roads, rivers, lakes, and wetlands, which affect the presence of pollinators. To overcome these problems, we used the ESTIMAP model to improve the results of the Lonsdorf model. For this, we included the effects of roads, railways, rivers, wetlands, lakes, altitude, climate, and ecosystem boundaries in the ESTIMAP modeling and compared the results with the Lonsdorf model. The results of the Lonsdorf model showed that the majority of Iran had a very low potential for providing pollination service and only three percent of the northern and western parts of Iran had high potential. However, the results of the ESTIMAP model showed that 16% of Iran had a high potential to provide pollination that covers most of the northern and southern parts of the country. The results of the ESTIMAP model for pollination mapping in Iran showed the Lonsdorf model of estimating pollination service can be improved through considering other relevant factors.

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Introduction

In recent years, there has been global concern about the decline of pollinators around the world (Viana et al., 2012). This concern has led to further studies identifying pollinator threats and quantifying the effects of pollinator reduction on pollinators in agricultural and natural systems. Approximately 75% of the world's agricultural products, known as human food, benefit from pollinators (Klein et al., 2007). Several studies have estimated the global economic value of pollination (Gallai et al., 2009), but these estimates are uncertain because the dependence of crops on pollinators is not fully understood. In Europe, the dependency of agricultural production on pollinating insects is about 84% (Williams, 1994). The high dependency of agricultural products on pollinators and the associated high economic value has led to the determination of the relative potential of land uses of Europe to provide pollination (Zulian et al., 2013).

Recent studies have shown that bees are more efficient pollinators than other pollinators because they both visit more flowers and put more pollen on the flower's stigmas (Willmer et al., 2017). Therefore, bees can be considered as the most important pollinators which are directly responsible for maintaining the diversity of native vegetation, as many plants are dependent on these species for their reproduction (Ollerton et al., 2011). Although farmers typically use honey bees to pollinate their crops, the recent decline in their activity and population (Potts et al., 2010) has led to a focus on wild bees and their function in nature. Some studies have shown that wild bees increase agricultural production considerably, especially in orchards (Garibaldi et al., 2013). Thus, wild bees are vital components of agricultural landscapes that provide essential services to farms and wild plants (Kennedy et al., 2013 250).

The two drivers that affect wild bee populations on farms are 1- Local management practices in the fields and 2- Quality and structure of the surrounding landscape (Klein et al., 2007). Various management practices such as organic farming and in-farm heterogeneity improve bee population even if the amount of natural habitat in the surrounding landscape is small (Batary et al., 2011). Research on the effects of landscape structure on pollinators focuses mainly on the role of the natural and semi-natural areas around farms, which provide foraging habitats and nesting sites for pollinators (Williams and Kremen, 2007).

Pollination depends on the movement of native pollinators from non-agricultural areas such as forests to farms (Ricketts et al., 2008). Therefore, the amount of habitat that bees visit during the day depends on the distance between foraging and nesting habitats and the configuration of these habitats (Kremen et al., 2004; Westrich, 1996). Large patches provide more biodiversity for pollinators (Tscharntke and Brandl, 2004), and as the size of these patches decreases, so does the abundance of pollinators (Aguirre and Dirzo, 2008). Decreased pollination has also been reported by increasing the distance from forest patches for the coffee plant (Boreux et al., 2013; Klein et al., 2003; Ricketts, 2004; Saturni et al., 2016). Several studies have shown that pollination decreases exponentially with increasing distance from natural and semi-natural forest patches within agricultural fields (Keitt, 2009; Martins et al., 2015; Mitchell et al., 2015; Ricketts et al., 2008). Ricketts et al. (2008) reviewed 23 studies examining the effects of landscape structure on pollination and found that the abundance and visiting rate of the bees decreased exponentially with distance from natural habitats.

The effects of roads on insects such as bumblebees have been reported negatively, and roads have acted as a barrier for them (Keller and Largiader, 2003), but their roles have not been considered in the Lonsdorf model. Phillips et al. (2020) examined 141 studies related to the effects of roads on pollinating insects. Their results showed that traffic and pollution caused by roads negatively affected pollinators. Muñoz et al. (2015) also examined the effects of roads on insects and reviewed 50 studies that reported these effects and found that fragmentation, pollution, accidents, and traffic caused by roads had adverse effects on the diversity and abundance of insects (Muñoz et al., 2015).

Riparian vegetation and wetlands have more pollinators than drylands and single-crop farms (Kuglerová et al., 2014 283). Santos et al. (2018) in their studied rivers found that the vegetation covers up to 300 m of the rivers supported more pollinators than near farms. Wetlands also play an important role in pollination by providing diverse nesting and foraging habitats for pollinators (McInnes, 2018). For example, there are more than 920 species of pollinating birds (Whelan et al., 2008), many of which depend on wetlands for part of their life cycle (McInnes, 2018). Ponds are also reported as a potential source of insects (Stewart et al., 2017). The high abundance of syrphids and bees has been shown in some ponds due to a high heterogeneity around them (Vickruck et al., 2019).

Wetlands surrounded by farms also have a high potential for pollination and as the distance from the wetland (75 m) increases, pollinators' abundance decreases in canola and cereal farms (Vickruck et al., 2019).

The ambient temperature affects pollinators' activity considerably (Zulian et al., 2013). Bees become inactive when the combination of temperature and sunlight reaches below a threshold (Corbet et al., 1993). Topographic microclimate also changes the plant-pollinator relationship through affecting flowering time (Olliff-Yang and Ackerly, 2020). Slope and aspect have significant ecological effects on vegetation patterns and consequently on pollinators by changing temperature and humidity (Bennie et al., 2008). As altitude increases, the population of many pollinators decreases (Devoto et al., 2005 293; Hodkinson, 2005 294; Kimball, 2008; Totland, 2001 296). Gottlieb et al. (2005) reported that with increasing altitude from 60 meters to 2000 meters, the abundance of wild bees decreased linearly. In areas with an altitude of more than 1000 m, the probability of the presence of *A.Flora* decreased in Iran (Parichehreh et al., 2020).

Habitats such as forest edges and flower-rich meadows are suitable areas for pollinators such as honeybees, solitary bees, bumblebees, and butterflies (Kells and Goulson, 2003; Svensson et al., 2000; Westphal et al., 2003). Woodlands and forests provide suitable nesting habitats and floral resources for pollinators and in particular, the forest edge has a higher value (Svensson et al., 2000). The mentioned studies have shown that the boundaries between habitats like forests and ranges have a higher potential for attracting pollinators than the habitat itself. Therefore, the boundary between these habitats should score higher in pollination mapping. For pollination mapping across Europe (Zulian et al., 2013), the edge of the forest was considered fixed, but the score decreased with increasing distance to the inner forest.

Action 5 of the EU Biodiversity Strategy requires its members to map and evaluate ecosystem services in their territories to 2020 (Maes et al., 2013). The purpose of this evaluation is to provide information for complex decisions. The processes that lead to the production of ecosystem services originate from spatial nature and these processes change in time and space (Burkhard and Maes, 2017). Therefore, determining the environmental conditions that affect wild bees at the landscape and local levels is critical (Kennedy et al., 2013). To map pollination service, Lonsdorf et al. (2009) presented a model that examines the spatial arrangement of nesting and foraging habitats of wild bees. In this model, for each land cover, the availability of nesting and floral resources is determined and pollination is estimated according to the foraging range of the desired species. The bees return to the nest after collecting pollen and nectar, so the visiting rate in a patch of floral resources depends on the distance between the patch and the nesting habitat (Lonsdorf et al., 2009). This model logically predicts pollination in a landscape (Kennedy et al., 2013), and is the first spatially explicit model in this field (Lonsdorf et al., 2009). This model is available in the Invest software (Integrated Valuation of Ecosystem Services and Trade-offs) (Sharp et al., 2014) and has shown acceptable efficiency in estimating pollination.

However, there are some significant criticisms about the Lonsdorf model (Groff et al., 2016; Olsson et al., 2015) because in this model, only the land use capacity in providing pollination is considered and other parameters affecting the presence of pollinators in a habitat are ignored. An applied methodology adopted by Zulian et al. (2013), known as the ESTIMAP model (Ecosystem services mapping at European scale), was used to map the pollination ecosystem across Europe, which in addition to the factors required to implement InVEST, has added several other factors to the model. For example, they used a land parcel system based on the Common Agricultural Policy Regionalized Impact to estimate the participation of crops in floral resource availability and the benefit of crops. They included the effects of some components like roads, water bodies, and climate in the process of pollination mapping based on the Lonsdorf model. These models use an expert assessment of different land covers to determine the availability of floral resources, foraging areas, and nesting habitats.

According to the above, the present study aims to estimate pollination in Iran based on the Lonsdorf model (Lonsdorf et al., 2009) and the ESTIMAP model (Zulian et al., 2013). We used additional factors such as climate, altitude, habitat edges, roads, lakes, wetlands, and rivers network in the ESTIMAP model. In this regard, after preparing the pollination map based on the Lonsdorf model, additional factors were summed with the primary map. Eventually, areas where pollinators were most likely to be absent, such as deserts and lakes, received zero points and were excluded from modeling.

Natural Geography of Iran

Iran is divided into three phytogeographical regions (Talebi et al., 2014 248): the Euxino-Hyrcanian, Saharo-Sindin region, and Irano-Turanian. Ecologists have divided Iran's forests into three ecological zones: Caspian or Hyrcanian, the Khalijo-Omanian, and Irano-Turanian, which are divided into Zagros mountainous and central plateau zones. Five ecological regions of Iran (Figure 1) are briefly introduced below.

Hyrcanian or Caspian ecological zone

Hyrcanian ecological region is located in the south of the Caspian Sea and along with the Alborz mountain range. The area of forest in this region is around 2400000 hectares in which 4 species of conifers, 50 species of shrubs and 80 species of broadleaf trees have been identified so far, which are mostly beech, hornbeam, oak, maple, and alder (Anonymous, 2008). These forests belong to the third geological period, which is considered a world natural heritage (Figure 1).

Irano-Turanian Ecological Zone

With an area of around 4666941 hectares, this region is divided into mountainous and desert areas that cover the central and western regions of Iran. Around 69% of the flora of Iran is located in this area and the main species of this region are pistachio, almond, and wild pear (Anonymous, 2008). The oak forests of the Zagros region with an area of nearly 5440494 hectares are estimated to be 5500 years old. This area is the most important Iranian oak forest (Figure 1).

Arasbaran Ecological Area

More than 775 plant species have been identified in this region, 55 of which have been reported for the first time from Iran. Therefore, UNESCO has protected these forests with an area of 174838 hectares since 1976 as one of the biosphere reserves. (Anonymous, 2008). The main species of the Arasbaran region are black oak, white oak, hornbeam, yew, and maple (Figure 1).

Khalijo- Omanian Ecological Region

The forests area of the Khalijo-Omanian forests close to the Persian Gulf and Sea of Oman shores which includes part of the southwest and all southern coasts of Iran, is 2039963 hectares. Varieties of Iranian acacia are the main plants of this region. Wetlands or mangroves that consist of two species *Avicennia marina* and *Rhizophora mucronata*, are also seen in this area.

Table 1 shows the area and proportion of Iran's natural resources. According to this table, forests, deserts, rangelands, and bushes cover 81 percent of Iran, among which rangelands cover almost half of the country most of it being poor rangelands. Deserts cover twenty percent of Iran, which are mainly found in the center, east, and southeast of Iran and the Irano-Turanian ecological region generally.

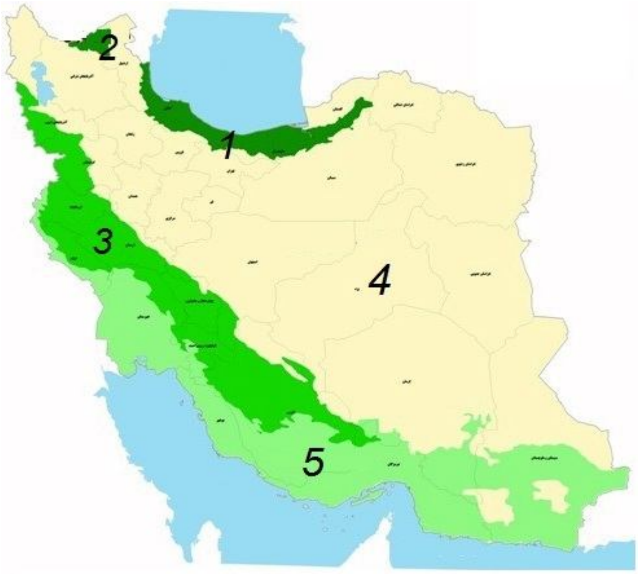

Figure 1. Phytogeographical regions of Iran (Euxino-Hyrcanian: 1 Caspian (Hyrcanian), 2 Arasbaran; Irano-Turanian: 3 Zagros, 4 Steppic central plateau, 5 Saharo-Sindian)

Table 1. Area and proportion of natural resources in Iran (Talebi et al., 2014)

Natural resources	Area (ha)	Proportion (%)
Natural forest	13,364,010	8.10
Plantation forest	946,546	0.57
Bush and woodland	2,723,756	1.65
Rangeland	84,960,321	51.60
Desert	32,863,972	19.94
Total	134,884,365	81.85

Agriculture in Iran

About 14.46% of Iran is covered by agricultural lands. In 2016, the area of agricultural lands in Iran was about 11 million hectares, of which 54% was irrigated and 46% was rainfed. The proportion of cereals was 69.55%, beans 7.27%, industrial products 5.02%, vegetables 4.71%, cucurbits 2.7%, fodder crops 9.44%, and other products 1.31%. The highest proportion in cereals consists of wheat (49.46%), barley (13.4%), alfalfa (5.91%), paddy (5.43%), chickpeas (4.57%), and fodder corn (1.81%). That is, about 80.58% of the crop harvest area belongs to these six crops (Agriculture, 2016). In 2015, the area of orchards in Iran was about 2.91 million hectares of which about 86.8% was irrigated and the rest was rainfed. The active area of the country's orchards was estimated at 2.46 million hectares, which was equivalent to 84.6% of the total area of the orchards. The five products that have the highest production in Iran are oranges, grapes, apples, cucumbers, and dates, respectively (Agriculture, 2015). Figure 2 shows the spatial distribution of forest, rangeland, and agricultural lands in Iran. According to this figure, agricultural lands can be seen in almost all over Iran, but the northeastern and western parts of Iran have a larger proportion of agricultural areas. As shown in Figure 2, parts of the eastern and central regions of Iran have no vegetation.

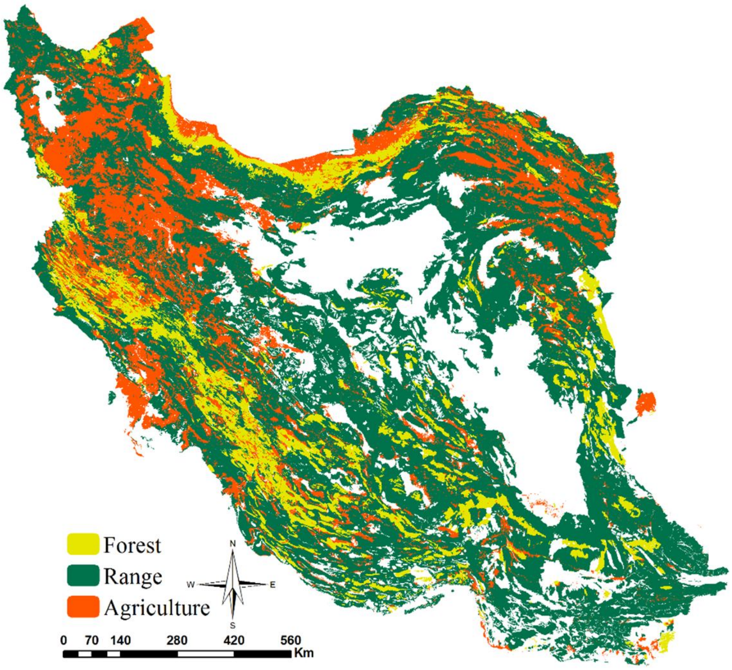

Figure 2. Coverage of forest, rangeland, and agriculture in Iran

Pollinating bees of Iran

There are about 800 species of wild bees in Iran belonging to the families Colletidae, Halictidae, Andrenidae, Melittidae, Megachilidae, Anthophoridae, and Apidae that are mostly found in temperate climates (Mohammadian, 2003). A wide range of pollinating bees has been identified in different parts of Iran. Among these, two species of *Apis florea* and *Apis mellifera meda* are widely distributed (Sanjerehei, 2014). *A. florea* is widespread in the southern parts of Iran, and *Apis mellifera meda* is native to Iran and has the highest distribution among other bees in the country (Rahimi and Mirmoayedi, 2013). The economic value of pollination of Iran's agricultural products in 2005-2006 was estimated to be about $6.59 billion of which $5.72 billion was the share of honeybees and $0.87 billion was the share of wild bees (Sanjerehei, 2014). It is estimated that pollinators affect 25% of the total agricultural products of Iran (Sanjerehei, 2014). In Iran, few studies have focused on the distribution modeling of wild bees while most studies have focused on the identification of species. For example, in a modeling study of the spatial distribution of *A. flora* species under the influence of climatic and topographic factors, Parichehreh et al. (2020) showed that the *A.florea* was seen from southeast to south and southwest of Iran and exhibited that the tropical climate with cold winters and hot summers were the most desirable areas for this species (Parichehreh et al., 2020).

In the present study, most of the articles that have studied wild bees in Iran have been reviewed, the results of which are summarized as follows. In a collective study of wild bees in Iran, Monfared et al. (2005) acknowledged that 34 species of Iranian bumblebees are found in twenty provinces of Iran (Monfared et al., 2005). In a comprehensive work on wild bees in Fars Province (southern Iran), Khodaparast and Monfared (2012) identified 177 species of which 56 species belonged to the Apoidea family, 49 species to Halictidae, 39 species to Megachilidae, 31 species to Andrenidae, one species to Melittidae, and one species to Colletidae (Khodaparast and Monfared, 2012). Izadi et al. (1999) also recorded 35 species of the Apoidea family in Fars Province (southern Iran). Khodaparast and Monfared (2013) reported 47 species of the Eucerine bees in Iran, all of which were in Fars Province (Khodaparast and Monfared, 2013).

Keshtkar et al. (2012) identified 25 species of wild bees in urban parks of Shiraz. Tavakoli Korqand et al. (2010) identified 46 species from 24 genera and 6 families of legume-crops pollinators in Guilan Province (northern Iran). Khodarahmi Ghahnavieh and Monfared (2019), identified 154 species, with 29 new species and 35 species of the family Andrenidae, 11 species of the family Apidae, 20 species of the family Colletidae, 50 species of the family Halictidae, 36 species of the family Megachilidae, and 2 species of the family Melittidae in the Isfahan Province. Salehi Sarbijan et al. (2012) identified 34 species of bees in Sistan and Baluchestan Province (southeastern Iran) belonging to 17 genera and 5 families.

Estimating Pollination based on the Lonsdorf model

The Londersf model focuses on wild bees and estimates their relative abundance on farms. Initially, using pollinating species habitat needs and food resources and the distances the species can travel, the model produces an indicator of the relative abundance of species in nesting habitats. In the next step, it predicts the abundance of each species in the agricultural fields. This model first measures the desirability or quality of patches that are suitable for bee nesting habitat according to the floral resources around these patches (Equation 1). In the assessment of food resources around nests, near pixels weigh more than the distant ones according to the expected flight distance of the bees. The result is a map showing the desirability of nests between 0 and 1.

$$G_i = N_i \frac{\sum_{j=1}^{M} F_j e^{-D_{ij/\alpha}}}{\sum_{j=1}^{M} e^{-D_{ij/\alpha}}} \tag{1}$$

In this Equation, if the habitat is suitable for nesting Ni equas 1 and otherwise equals 0. D_{ij} is the Euclidean distance between nesting cells (i) and floral resource cells (j). The numerator is the total weight of the distance between all the cells of the floral resources adjacent to the nest patches and the quality of these cells (F_j) is between 0 and 1. α determines the average distance that the bees can travel. The result of this equation is a map that shows the fitness of the patches for bees to nest ranging between the numbers 0 to 1. In the next step, the model predicts the relative abundance of visiting bees in agricultural fields according to the desirability of the nests (Equation 2).

$$P_j = \frac{\sum_{j=1}^{M} G_i e^{-D_{ij/\alpha}}}{\sum_{j=1}^{M} e^{-D_{ij/\alpha}}} \tag{2}$$

Table 2. Floral availability and nesting suitability scores for Iran land covers.

Land use/cover	Nesting suitability	Floral availability
Irrigated Agriculture	0.2	0.5
Rainfed agriculture	0.2	0.2
Orchard	0.2	0.8
Abandoned orchard	0.4	0.2
Fallow	0.3	0.3
Broad-leaved forest	0.8	0.7
Aleppo oak	0.6	0.6
Low-density forest	0.4	0.3
Woodland	0.5	0.4
Natural grasslands	0.7	0.9
High-quality range	0.6	0.8
Poor range	0.3	0.4
Bare soil	0.2	0
Rocky lands	0	0
Desert	0	0
Urban	0.2	0.1
wetlands	0.3	0.5
Lakes	0	0
Shoreline	0	0
Dune	0.1	0
Salt land	0	0

we used the bee activity index as a representative of the climate component (Equation 4). The activity index is calculated using Equation 4 as follows.

$$A\ (\%) = -39.3 + 4.01\ T_{blackglobe} \quad (4)$$

In this equation, $T_{blackglobe}$ represents the temperature in a spherical black model that mimics the body temperature of an insect. This temperature is based on a function of ambient temperature T (°C) and solar irradiance (Equation 5) (Corbet et al., 1993).

$$T_{blackglobe} = -0.62 + 1.027\ T + 0.006\ R \quad (5)$$

$$S = \sum (w_i\, x_i) \prod C_j \quad (3)$$

where, S, X_i, W_i, and C_j are the suitability value, the score of criterion i, the weight of criterion i, and the score of constraint j, respectively.

Corbet et al. (1993) developed a model for pollinator activity based on the proportion of active bees. Their index used temperature and solar irradiance, which estimates the activity of solitary bees on average between 0 and 100% per year (Zulian et al., 2013). In the present study,

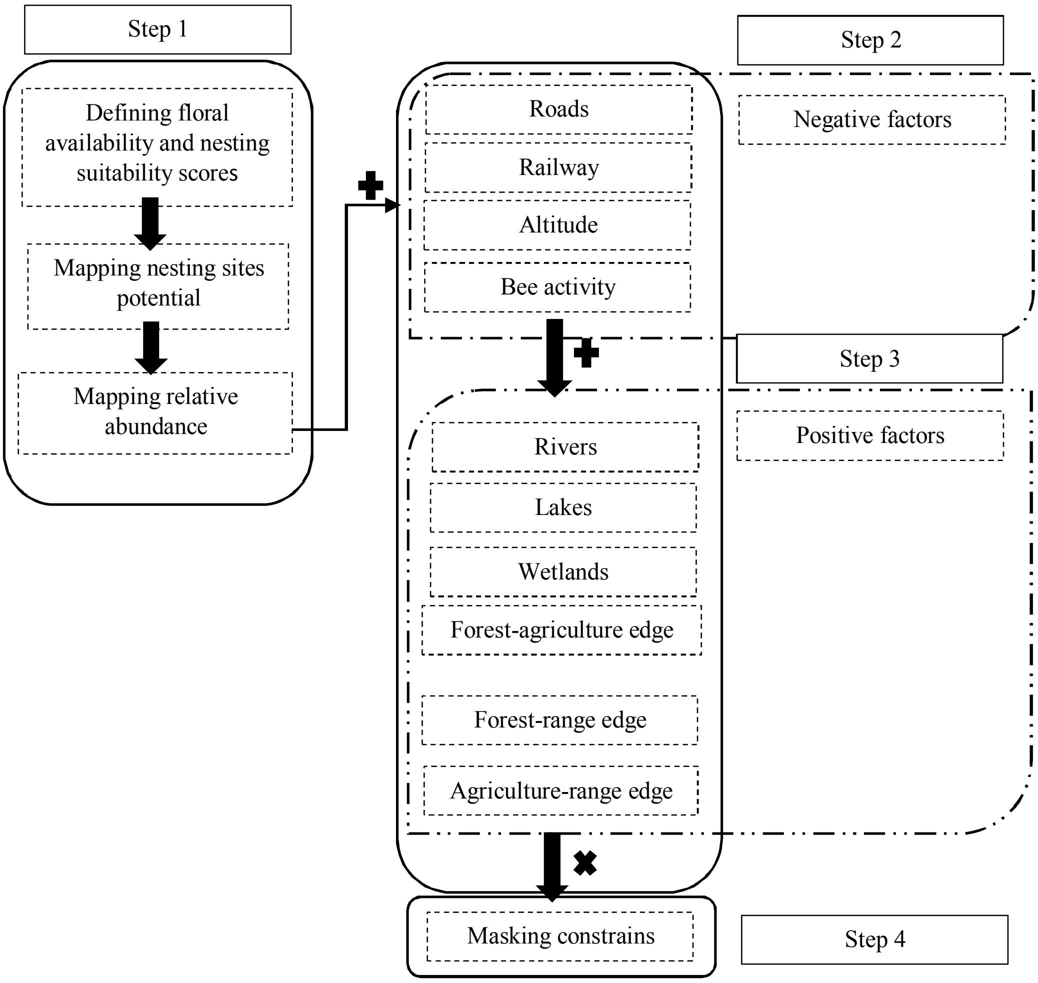

Figure 3. Modeling steps in the ESTIMAP for pollination mapping in Iran.

To determine the abundance of bees in farms, based on the framework of Equation 1 the Lonsdorf model assumes that cells from farms that are closer to the nesting habitats are more suitable and therefore have more bee abundance. Therefore, the abundance index of P in j cells is calculated according to Equation 2, in which G_i shows the fitness of nesting patches, which was calculated in the previous step. In the present study, according to experts' opinions, a distance of 1000 meters was considered as foraging distance (α). for scoring different land covers in the Lonsdorf model, the numbers are given between zero and one (Table 2), where 0.5 means 50% of the desired habitat provides floral or nesting habitat (Lonsdorf et al., 2009).

Estimating Pollination based on the ESTIMAP model

A weighted linear combination (Eastman, 2012) was used to add the additional criteria to the Lonsdorf model's output. In the weighted linear combination method (Equation 3), criteria are categorized into factors and constraints (Eastman, 2012). The factor is a measure that increases or decreases the appropriateness of an option for the intended purpose. Constraints are criteria that limit the decision option with zero and one values. Factors affecting the presence of pollinators in the present study are presented in Figure 3.

Figure 3 shows the four steps of the ESTIMAP model for pollination mapping in the present study. In the first step, a preliminary map was prepared based on the Lonsdorf model. At this step, the quality of nesting habitat patches was first calculated according to the available food around patches. Then, the pollinators' abundance was determined according to the quality of nesting habitat patches in the whole landscape. At this step, we used the opinions of experts to score different land covers in providing nesting habitat and floral resources. In the second step, factors such as roads, railways, altitude, and climate that affected the activity of bees were added to the model. A 500-meter buffer to roads and railways was considered as a negatively impacted area. Because the presence of pollinators increases with decreasing altitude and increasing temperature, we standardized the altitude and bee activity index between 0 and 1, where value one indicates high altitude and high bee activity. The mentioned criteria in the second step were assigned a weight and summed with the map of the first step (Equation 3). In the third step, the edges of habitats such as rivers, wetlands, and lakes ranging from 1000 to 1500 meters were considered as appropriate buffer for attracting pollinators. Due to their importance, the forest-agriculture, forest-rangeland, and agriculture-rangeland edges in the range of 2000 meters received weight and were summed with the obtained map in the second step. In the last step, all areas in which pollinators were unlikely to be present were removed from the map and were assigned value zero.

Results

Figure 3 shows the relative pollination potential map of Iran's land cover based on the Lonsdorf model. In this figure, areas with a high potential for pollination, have value one and are shown in a light color. An overview of this map shows that the majority of Iran is covered by areas with low potential for pollination whereas areas with high pollination potential are distributed sparsely in Iran. The northern regions in the south of the Caspian Sea and along the Alborz mountain range with dense forests and rangelands have a high potential for pollination. The western and southwestern regions along the Zagros Mountains also have a high potential for pollination as in these areas the forests are not very dense and the areas around the trees are covered by high-quality rangelands that provide suitable foraging habitat for pollinators. Figure 4 shows a classified map of pollination potential in Iran based on the Jenks natural breaks method (Jenks, 1977) that minimizes intra-class variance while maximizes inter-class variance. As can be seen, this map is divided into five classes, two classes of very low and medium, occupy a higher proportion of Iran than the other classes (Table 4). According to Table 4, about 77% of Iran (Irano-Turanian ecological area in general) has very low to low potential in providing pollination that covers most of the arid and desert areas of Iran in the center, east, and southeast.

Figure 5 shows the relative pollination potential map in Iran based on the ESTIMAP model. According to this figure, a large part of Iran is covered by areas with low to medium potential for pollination, located mainly in the eastern and central regions, where relatively sparse vegetation can be seen. Areas with high potential are seen in the north and southwest of Iran, which are shown in a light color. Figure 6 shows a classified map of pollination potential in Iran based on the ESTIMAP model in five classes. In this figure, the very low to moderate classes have the highest share and the very high class has the lowest proportion (Table 5). The moderate class almost covers the southern regions of the country (Khalijo- Omanian), which were considered as a very low class in the Lonsdorf model. According to the ESTIMAP model (Table 5), about 84% of Iran has very low to moderate pollination potential, which covers most of the arid and desert areas of Iran in the center, south, east in the Irano-Turanian and the Khalijo-Omanian ecological areas. Land uses with a high potential for pollination cover about 16 percent of Iran, located in the Hyrcanian ecological areas in the north, Arasbaran in the northwest, and the southern part of the Zagros region in the Irano-Turanian region.

About 30% of Iran consists of land uses with moderate potential to provide pollination, which includes the Hyrcanian ecological areas in the north, Arasbaran in the northwest, and the Zagros part of the Iranio-Turanian region. As mentioned in earlier in this paper, these areas include forest in Iran with the highest biodiversity. About 0.54% of Iran was found to be the pollination hotspots in the current study.

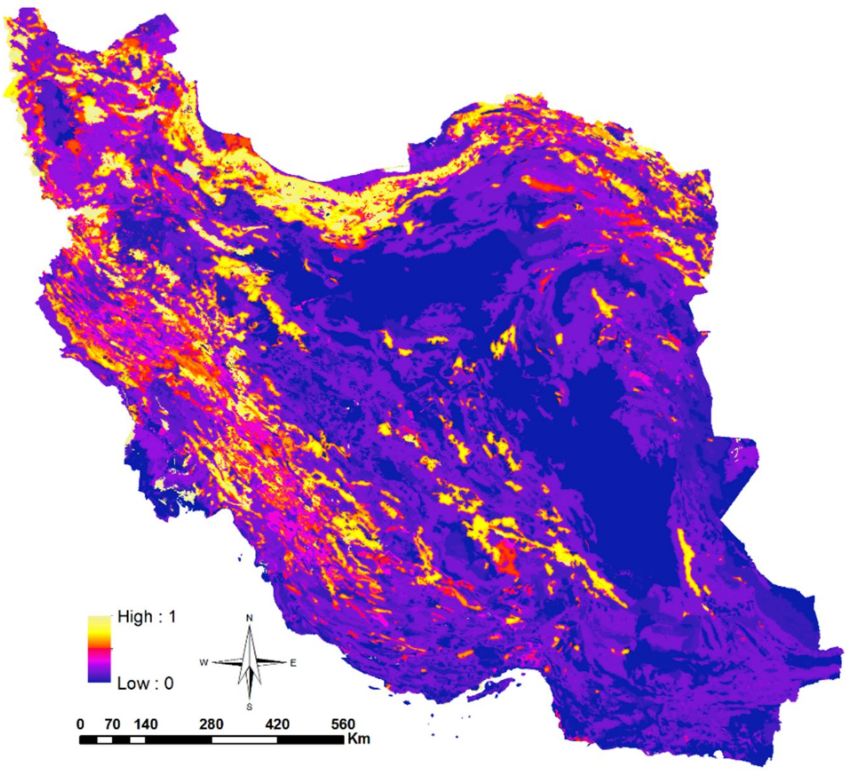

Figure 3. The map of the relative pollination potential according to the Lonsdorf model.

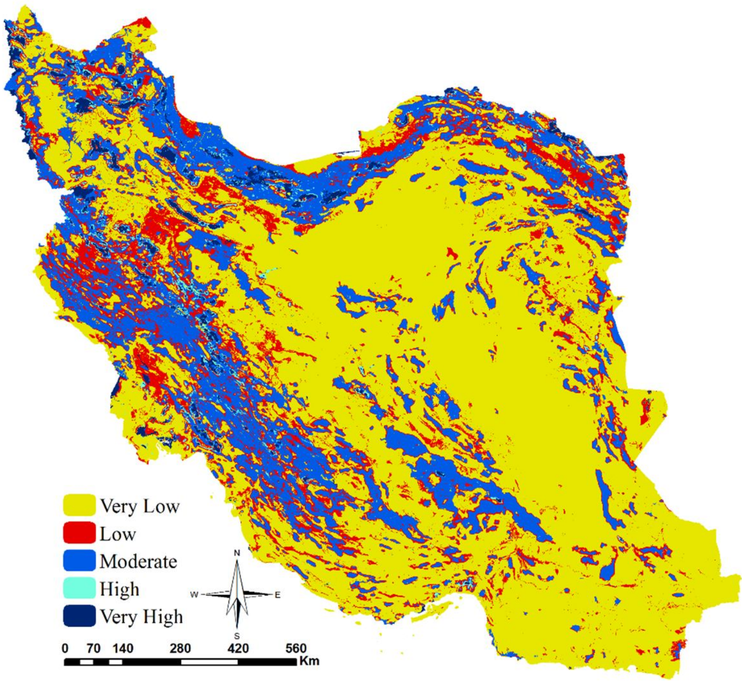

Figure 4. The classified map of the relative pollination potential according to the Lonsdorf model

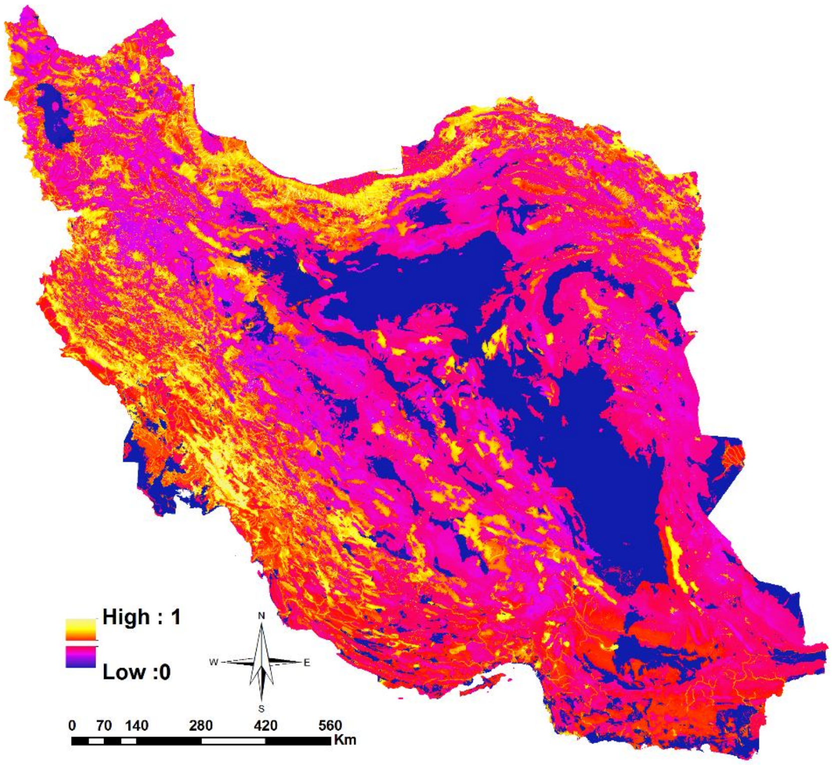

Figure 5. The map of the relative pollination potential according to the ESTIMAP model.

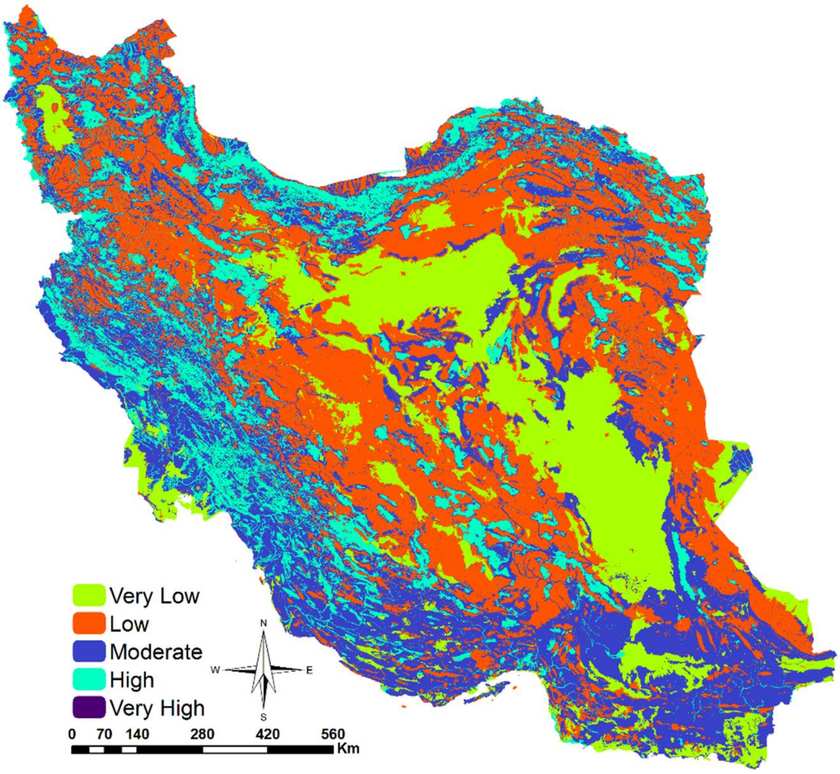

Figure 6. The classified map of the relative pollination potential according to the ESTIMAP model.

Table 4. The area and proportions of pollination classes for the Lonsdorf model

Pollination supply classes	Area (Ha)	Proportion (%)
Very High	3034680	1.86
High	2055016	1.26
Moderate	32986632	20.28
Low	23156164	14.24
Very Low	101378856	62.34

Table 5. The area and proportions of pollination classes for the ESTIMAP model

Pollination supply classes	Area (Ha)	Proportion (%)
Very High	891196	0.57
High	24734736	15.24
Moderate	49201552	30.32
Low	57627336	35.52
Very Low	29778632	18.35

Discussion

An important part of the results of the present study was influenced by experts' opinions because the Lonsdorf model estimates pollination according to the potential of land covers in providing pollination determined by expert opinion in different steps. Therefore, the results of such models may have significant uncertainty due to varied expert opinions. Our results showed that there was a significant difference between the models adopted by the present study in estimating pollination. The results of the Lonsdorf model showed that most of Iran (77%) was covered by regions with low potential for pollination mainly located in the southeast, east, and center of the country. Based on this model about 20% of Iran had moderate potential in providing pollination and about 3% had high potential. However, The Lonsdorf model has been developed for predicting the presence of pollinators at the landscape level concerning nesting and foraging habitats ignoring on-farm management practices and landscape configuration (Kennedy et al., 2013). The Lonsdorf model is not influenced by the spatial arrangement of nesting and foraging patches, meaning that it does not explicitly take into account the landscape configuration. However, larger patches receive higher values in this model as the first step in estimating pollination in this model is to determine the suitability of the nesting patches and the surrounding floral resources. Thus, the central cells of the nesting patches receive a higher score than the marginal cells. Besides, the proximity of high-quality nesting patches to each other will increase their score. Therefore, habitat connectivity positively affects pollination.

The results of the ESTIMAP model showed that 55% of Iran had little potential in providing pollination located mostly in the central and northwestern desert regions. About 30% of Iran had moderate potential to provide pollination mainly located in the southern and eastern regions of Iran. About 16% of the country was found to be covered by areas with high potential for pollination in the broad-leaved northern forests and the warm southwestern regions. A comparison of the results of this model with the Lonsdorf model showed that there was a significant difference in the results of these approaches. The most important difference was seen in the areas with a high potential for pollination, in the Lonsdorf model these areas constituted 3% of Iran but in the ESTIMAP model, the proportion was 16%. In the very low and low classes, there was a 20% difference, as the Lonsdorf model identified about 77% and the ESTIMAP model estimated about 54% of Iran as areas with low potential for pollination. The reason for this difference was that the ESTIMAP model included additional factors such as roads and rail networks, altitude, and climate in its modeling, but the Lonsdorf model was solely based on land covers potential in providing nesting and foraging habitat.

In the ESTIMAP model, it was assumed that pollination was a distance-based ecosystem service that decreases exponentially by distance from nesting habitats (Mitchell et al., 2015). Therefore, according to the foraging range of bees, the pollination rate increased at the border of two ecosystems such as forests and rangelands. Based on other studies (Zulian et al., 2013), we expected more pollinators at the border of ecosystems. However, the Lonsdorf model assigns lower scores to these areas, and therefore, we had the minimum estimation of pollination for these areas. According to the Lonsdorf model, the probability of pollinators' presence decreases at the edges of land covers, while at the forest-rangeland boundary, a high probability of pollination is estimated (Zulian et al., 2013).

One of the important factors in estimating pollination is the marginal effect of influencing factors on the presence of pollinators. In the Lonsdorf model, for water bodies, the score of nesting and foraging habitat was considered to be zero, but as mentioned in the introduction section, riparian areas of wetlands and lakes provide suitable habitat for pollinators which usually have a positive effect up to a distance of 300 meters (Santos et al., 2018). The Lonsdorf model ignores linear phenomena such as rivers and road networks and their edge effects because these linear phenomena are usually absent in land use maps, and therefore, it is not possible to take them into account.

Conclusion

Various studies have claimed that pollination depends on nesting habitats and floral resources, and consider the existence of these two factors as a vital need for pollinators. Currently, the most common model for estimating pollination is the Lonsdorf model, which is included in InVEST software. This model uses the potential of each cover in providing pollination, and estimates the pollination in the entire landscape. The present study showed that it was not enough to rely solely on land covers in which the presence of pollinators was high. We showed that other important factors such as altitude and climate had a significant impact on the results and emphasized considering these factors in future modeling. Some covers are sometimes given a high score in the

Lonsdorf model, while the cover may be located in very cold weather or at a high altitude where pollinators are less likely to be present. Therefore, the results of the Lonsdorf model may not be as accurate as desired. Another criticism about the Lonsdorf model is that it gives low value to ecotones in providing pollination while the borders of forests and rangelands are highly desirable for pollinators. The reason for this is that in a landscape with uniform distribution of resource patches, bees travel near their nesting areas to reduce energy and time consumption and increase foraging efficiency (Heinrich, 2004). Therefore, at the border of the forest and rangeland, bees have access to nesting and foraging habitat and spend less energy traveling longer distances. Hence, the ESTIMAP with other important factors included in our study provided a better view of the pollination services for Iran.

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