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Mapping Priority Areas for Apiculture Development with the Use of Geographical Information Systems

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Abstract: Supporting local and central authorities in decision-making processes pertaining to environmental planning requires the adoption of scientific methods and the submission of proposals that could be implemented in practice. Taking into consideration the dual role that honeybees play as honey producers and crop pollinators, the aim of the present study is to identify and utilize a number of indicators and subsequently develop priority thematic maps. Previous research has focused on the determination of, and, on certain occasions, on mapping, priority areas for apiculture development, based mainly on the needs of honeybees, without taking into consideration the pollination needs of crops that are cultivated in these areas. In addition, research so far has been carried out in specific spatial entities, in contrast to the current study, in which the areas to be comparatively assessed are pre-chosen based on their geographical boundaries. The information derived from this process is expected to help decision-makers in local and regional authorities to adopt measures for optimal land use and sound pollination practices in order to enhance apiculture development at a local scale. To achieve this target, the study incorporates literature about the attractiveness of crops and plants to pollinating honeybees as well as the pollination services provided by honeybees, in combination with detailed vegetative land cover data. The local communities of each municipality were comparatively evaluated, by introducing three indicators through numerical and spatial data analysis: Relative Attractiveness Index (RAI), Relative Dependence Index (RDI), and Relative Priority Index (RPI). Based on these indicators, attractiveness, dependence, and priority maps were created and explained in detail. We suggest that a number of improvement measures that will boost pollination or honey production or both should be taken by decision-makers, based on the correlations between the aforementioned indicators and the exanimated areas. In addition, dependence maps can constitute a powerful tool for raising awareness among both the public and the farmers about the value of honeybees in pollination, thus reinforcing bee protection efforts undertaken globally. Attractiveness maps that provide a thorough picture of the areas that are sources of pollen and nectar can serve as a general guide for the establishment of hives in areas with high potential for beekeeping.

Keywords: apiculture development indicators; honeybee pollination; GIS mapping

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1. Introduction

Ecosystems provide a wide range of products and services that are vital to supporting all human life and activity and play a fundamental role in maintaining human well-being, as well as future economic and social development. These ecosystem services can be grouped into the following categories: (a) provisioning, through which we enjoy goods, such as food, water, timber, pharmaceuticals, raw materials for industrial products, etc.; (b) regulating, i.e., services that, by acting as regulators, maintain a world in which it is possible for man to live and provide benefits, such as pollination of crops and wild plants, extreme weather mitigation (e.g., flood disasters), and stabilization of the climate; (c) cultural, such as man's admiration for natural beauty, inspiration, and recreation, and everything that contributes to man's spiritual well-being; and (d) supporting, such as soil formation, photosynthesis and oxygen production, and water cycle and nutrient cycles that support growth and production [1]. Policy-makers design strategies that foster the creation, development, and preservation of land uses associated with enhanced ecosystem services. In parallel, a great part of these policies aims at promoting social and economic goals including the reduction in poverty and social inequalities [2]. Policy-makers' strategies favor specific land uses and, at the same time, provide financial incentives that will ultimately lead to ecosystem conservation. Apiculture is a very important branch of agriculture both on the grounds that it directly contributes to a country's Gross Domestic Product (GDP) and because the contribution of bees to the increase in crop production is priceless. In particular, beekeeping takes advantage of the existing flora and vegetation of an area in a manner that protects the area from deforestation or competition with other alternative land uses [3–5]. In 2016, the United Nations Intergovernmental Panel on Biodiversity and Ecosystem Services placed great emphasis on how vital it is for local populations to be aware of the threat of loss of pollinators and on the alert for its numerous impacts [6].

Insect pollinators are essential for the production of fruits, vegetables, and animal feeds in agricultural ecosystems [7]. Many plant species rely for their survival on insects that transport pollen grains from flower to flower. In the United States, the honey bee (*Apis mellifera*) is the most common pollinator of agricultural crops and, thus, the most important bee species for domestic agriculture [8]. Honeybees also contribute substantially to the biodiversity of the forest flora [9]. In Europe, pollinators (honeybees, bumblebees, and solitary bees) contribute at least 22 billion euros a year to the European agricultural industry, and they ensure the pollination of many crops and wild plants [10]. With 147 hives per beekeeper, according to 2018 statistics, Greece ranks first in density and number of hives per beekeeper, compared to other European countries [11]. However, there are no data available on the value of pollination services in this country. Current policies and high-energy demands have caused an increase in cultivated land with insect-dependent crops such as biofuels, increasing, at the same time, the demand for pollination services [12]. A comprehensive study concerning developing countries showed that crop yields could be enhanced at a low cost through high densities of crop pollinators (for fields <2 ha), as well as by adopting actions to boost biodiversity in larger fields [13]. Pollinator diversity is declining in many parts of the world, mainly due to intensive agricultural practices, monoculture, overuse of pesticides, and high temperatures associated with climate change [14]. In addition to these reasons, the survival and productivity of honeybees depend on varroa mite populations, bee viruses, beekeepers' practices, and the nutrition of honeybees [15] in combination with other factors such as the presence of diseases and parasites [16]. A pan-European epidemiological study conducted between the fall of 2012 and the summer of 2014 (EPILOBEE) revealed that the survival of bee colonies depends on the proper training of beekeepers and the control of diseases through beekeeper practices [17]. The monitoring program concerning honey bee colony mortality carried out by the Global Scientific Organization "COLOSS" showed that small beekeeping businesses (up to 50 hives) suffered higher winter losses than the larger ones [18–20].

Alaux et al. [21], in order to assess bee health in relation to floral landscapes, used geographical information on permanent semi-natural habitats obtained from the French National Institute (Institut Geographique National), which they processed with Quantum GIS software for the quantification of landscape quality within a radius of 1.5 km from the hives. Amiri and Mohamed Shariff [22] evaluated the suitability of land use for beekeeping, using geographic information systems (GIS) and the approach adopted by Food and

Agriculture Organization of the United Nations (FAO). They used criteria such as type of vegetation cover (composition, attractiveness, and flowering period), climate (temperature and rainfall), road access, and the available water resources, in order to map suitable land-use types. Zoccali et al. [23] mention that honeybees are critically important for the environment and the economy, and they have developed a rapid method for identifying areas suitable for beekeeping aiming to maximize productivity and reduce the risk of colony loss. A new approach based on GIS was tested and implemented in the region of Calabria, southern Italy, and a land map showing the potential suitability for beekeeping activity was developed. Samuelson and Leadbeater [24] classify techniques for land categorization covered by plants of greater or lesser beekeeping interest into: (i) simple visual classification, (ii) one-stage geographic information systems (GIS-based classification), and (iii) upgraded classification based on geographic information systems (GIS-based-refined classification). The latter was considered the most appropriate of the three, as it includes field data on the type of flowering and the flowering period. Ausseil et al. [25] have assessed and mapped monthly supplies of pollen and nectar using GIS. This tool could help beekeepers to make sound decisions about seasonal transportation to ensure colony nutrition throughout the year.

The aim of the current research is to determine numerical indicators for the comparative evaluation of the selected areas and to create thematic maps, on the basis of recommended actions to be taken for the development of beekeeping. The degree of priority for apiculture development was determined after comparative evaluation based on the available food sources and the dependency of the plant species on honeybee pollination. To achieve this goal, in contrast to the approaches adopted in other studies, which mainly concerned the selection of suitable geographical zones for beekeeping within a given spatial unit, in the present study, the areas to be assessed are pre-chosen based on their geographical boundaries. This delimitation is expected to help local (municipalities) and regional (regional unit) authorities adopt measures for apiculture development at a local scale, regardless of the fact that the flight of honeybees is not restricted from geographical boundaries. In addition, dependence maps, which depict with varying intensity the dependence of entire areas on honeybees for pollination purposes, can constitute a powerful tool for raising awareness among both the public and the farmers about the value of honeybees in pollination, thus strengthening bee protection efforts undertaken globally. Attractiveness maps provide a thorough picture of the areas that are food sources for bees at a local community level and, for this reason, they can serve as a general guide for the establishment of hives in areas with high potential for beekeeping.

2. Materials and Methods

2.1. Research Area

The research area is located in the Regional Unit of Pella in Northern Greece (Appendix A), comprising the municipalities of Almopia, Edessa, Pella, and Skydra, which include a total of 89 municipal communities (municipal units and local communities). This area was chosen because it is of great beekeeping interest due to its high plant species diversity: there are four distinct vegetation zones, a rich variety of agricultural crops (peach, cherry, apple, cotton, etc.), as well as a significant number of forest and herbaceous plants. More specifically, the four vegetation zones distinguished (in order of increasing altitude) are as follows: (a) Quercetalia Pubescentis, (b) Fagetalia (dominated by beech-fir forests and mountain conifers), (c) Vaccinio—Picetalia (the zone of cold-hardy conifers), and (d) Astragalo—Acantolimonetalia (with non-forested high mountain meadows and grasslands). The most interesting tree and shrub species for apiculture in the Prefecture are oak (*Quercus pubescens*, *Quercus conferta*, *Quercus cerris*, *Quercus coccifeta*, and *Quercus ilex*), pine (*Pinus nigra* and *Pinus sylvestris*), and chestnut (*Castanea sativa*) and Paliurus (*Paliurus spina christi*). Herbaceous species include: *Trifolium pratense*, *Asphodelus ramosus*, *Trifolium repens*, and *Cistus incanus*.

2.2. Methodological Steps

The following methodological steps were used:

Numbered lists can be added as follows:

1. Collect, process, and analyze spatial information and numerical data concerning the cultivated and forest areas.
2. Collect published data mainly from the documents issued by the USDA Agricultural Research Service [26], focusing on the attractiveness (supply of pollen and/or nectar) of agricultural crops to pollinating bees from the various plant species growing in the research area.
3. Collect data concerning the dependence of plant species on pollinators and, in particular, on honeybees for main crop production, not for breeding and seed production if seeds are not the main consumer product.
4. Determinate numerical indicators on a scale from 0 to 1, for the comparative evaluation of the predefined areas.
5. Create thematic maps to be considered prior to undertaking apiculture development interventions.

According to this approach, municipal units and local communities are classified as more or less eligible for the implementation of beekeeping development measures, using the criteria and sub-criteria presented in Table 1.

Table 1. Criteria for evaluating priority areas.

Criterion	Unit
Agricultural areas	Crop species. Cultivated forest species (*Robinia pseudoacacia*, *Paulownia tomentosa*, and *Castanea sativa*).
Natural grasslands	Deciduous shrubs (sparse or dense *Paliurus spina christi* and *Quercus coccifera* clusters located in grassland and pasture areas) combined with melliferous flora such as *Asphodelus ramosus*, *Trifolium repens*, *Cistus incanus*, etc.
Forest areas	Oak, chestnut forests, and *Pinus brutia* saplings.
Analysis of covered area in terms of agricultural plant species and forest species	Land cover (ha).
Attractiveness to honeybees	Pollen supply (values range from 0 to 2). Nectar supply (values range from 0 to 2).
Honeybee pollination dependence	Honeybee dependence (values range from 0 to 1).

For the implementation of the first step listed above, a large volume of data from heterogeneous sources were collected, processed, and analyzed. More specifically, the numerical data on the cultivated areas per crop for year 2018 were retrieved from the statistics of single agricultural holdings, which are available on the official website of the Greek Payment Authority of Common Agricultural Policy Aid Schemes (OPEKEPE). As for the forest and pasture areas examined, spatial information on land cover with forest species was used from the vegetation and land use maps made available by the Regional authorities of Central Macedonia and owned by the Hellenic Ministry of Environment and Energy, as well as the background of the boundaries of the municipal units and local communities in vector form, which was retrieved from the official website of the General Secretariat for Water, a department of the Hellenic Ministry of Environment and Energy. The conversion of spatial information into numerical data was performed by means of GIS. The software that enabled us to analyze and edit spatial information was QGIS, a free and open-source geographic information system. The spatial heat maps of relative attractiveness, relative dependence, and relative priority indices were created using the Inverse Distance Weighted (IDW) interpolation method with a resolution of 200 m (attainment of the 5th methodological step). The thematic and spatial resolution of the maps is 300 dpi, with page width of 3507 px and page height of 2480 px. The IDW method is a deterministic interpolation method that derives the value of a variable at some new location using values obtained from known locations. The use of Geographical Information System (GIS)-based software and spatial analysis with IDW interpolation enabled the mapping of, attractiveness, priority, and dependence in the research area of Pella. In the IDW method, it is assumed that the rate of correlations and similarities between neighboring points (i.e., the index values corresponding to the centroid of Municipal Local Communities areas) is proportional to the distance between them. It is assumed that this correlation can be defined as a reverse distance function of every point from neighboring points. The visual representation of the aforementioned indices through the use of IDW method is robust and constitutes an accurate representation of the spatial mapping of index values in the municipalities under study, compared to the presentation of index values at the municipality level. The main reason is that it is more rational to assume that the indices are not confined within the specific municipality boundaries, hence assuming that there is interdependence between indices from neighboring municipalities. The accuracy of land cover data with vegetation can be considered excellent leading to the creation of a "vegetation pattern" in the selected spatial units, given that: (a) the land cover data used solely in the case of forest species were tested on a random basis for their correctness through on-site visits and cross-checked with the results of another research project conducted in the area, which concerned the Paliurus bee forages on Paiko Mountain [27], and (b) the numerical data of land cover with agricultural crops have been derived from the Single Farm Payment (SFP) statistics for 2018, in which the exact size of the area as well as the species cultivated in the agricultural lands of each Municipal Unit/local community are declared in detail.

For the realization of the second methodological step, data on pollen and nectar supply were used, mainly from the document issued by the USDA Agricultural Research Service, focusing on the attractiveness of agricultural crops to pollinating bees for the collection of nectar and/or pollen [26].

In the third methodological step, estimating the proportion of honeybee pollinators to the total of pollinators (honeybees, solitary bees, bumblebees, hoverflies, etc.), is subjected to a number of uncertainties, such as different areas, method of measurement, varying conditions, available number of hives, and different varieties. However, such percentages were used in the past. For instance, the degree of agricultural production dependence on pollinators and the percentage of honeybee pollinators have been estimated with the use of a model based on the increase in production of 40 basic crops in the United Stated. These data have been used to assess the value of honeybee pollination services [28]. In another approach, for each different crop pollinated by honeybees, the following ratio was used: number of hives available divided by the number of hives that could possibly replace all pollinators (according to international data on hive density required for each crop) with the aim of reviewing the "traditional" percentage of honeybee pollinators as introduced by Morse and Calderone (2000) and thus recalculate the proportional production value derived from pollination with honeybees [29]. The calculation of the value of pollination services attributed only to honeybees is also reported by Borneck and Merle [30]. Dependence ratios of agricultural production directly on honeybees were also used in a study estimating the value of pollination services in Australia using the generalized partial equilibrium model [31]. In the present study, as there are no specific values available for the participation of honeybees in the pollination process in Greece, the potential proportion of honey bees in pollination processes was given after a systematic review of published research articles in combination with empirical observations performed in the study area, the results of which are included in Table 2:

Table 2. Crop dependence on pollinators and participation of honeybees in pollination process.

Crop	Mean Dependence Ratio (D) [1]	Potential Proportion of Honeybees into Pollination Process (P_{HB}) [2]	References/ Notes
Alfalfa (*Medicago sativa*)	0	0	[32]
Almonds (*Prunus dulcis*, *Prunus amygdalus*, and *Amygdalus communis*)	0.65	0.7	[28,33–35]
Apples (*Malus domestica*)	0.65	0.7	[34,36–38]
Apricots (*Prunus armeniaca*)	0.65	0.7	[34,35,39]
Barley (*Hordeum vulgare* L.)	0	0	[26,40]
Beans (*Phaseolus* spp.)	0.05	0	[26,41,42]
Chick peas (*Cicer arietinum*)	0	0	[26]
Common wheat (*Triticum aestivum*)	0	0	[40]
Corn (*Zea mays*)	0	0	[26]
Cotton (*Gossypium hirsutum*, *G. barbadense*, *G. arboreum*, and *G. herbaceum*)	0.25	0	[34]
Cucumbers and Gherkins (*Cucumis sativus*)	0.65	0.9	[34,43]
Durum Wheat (*Triticum durum*)	0	0	[40]
Eggplants (*Solanum melongena*)	0.25	0.5	[44]
Garden pea and field pea (*Pisum sativum* and *P. arvense*)	0	0	[45]
Grapes (*Vitis vinifera*)	0	0	[26,42]
Hazelnuts (*Corylus avellana* L.)	0	0	[42,46]
Kiwifruit (*Actinidia deliciosa*)	0.95	0.7	[34,47,48]
Lentils (*Lens esculenta* and *Lens culinaris*)	0	0	[42]
Melon seed (*Cucumis melo*)	0.95	0.5	[49]
Oat (*Avena sativa*)	0	0	[40]
Okra (*Abelmoschus esculentus*)	0.25	0 (*NA)	[50]
Olive (*Olea europaea*)	0	0	[42]
Peaches and nectarines (*Prunus persica* and *Persica laevis*)	0.65	0.5	[34,51–53]
Pears (*Pyrus communis*)	0.65	0.7	[34,42,52,54,55]
Persimmons (*Diospyros kaki*; *D. virginiana*)	0.05	0	[56]
Plums (*Prunus domestica* and *P. spinosa*)	0.65	0.7	[34,35,54]
Pumpkin, squash, and gourds, (*Cucurbita maxima*, *C. mixta*, *C. moschata*, *C. pepo*)	0.95	0.7	[34,57]
Quinces	0.65	0.7	[58]
Rapeseed including canola (*Brassica napus*)	0.25	0.5	[59]
Chilies and peppers (*Capsicum annuum*)	0.05	0	[26,44,60]
Rye (*Secale cereale*)	0	0	[26,40]
Sesame (*Sesamum indicum*)	0.25	0.7	[61]
Soybeans (*Glycine max* and *G. soja*)	0.25	0.7	[62]
Spinach (*Spinacia oleracea*)	0	0	**
Strawberries (*Fragaria* spp.)	0.25	0.5	[63,64]
Sunflower (*Helianthus annuus*)	0.25	0.7	[65]
Sweet cherries (*Prunus avium*)	0.65	0.5	[66–70]
Sweet chestnuts (*Castanea sativa*)	0.25	0.2	[34,71,72]
Tomatoes (*Lycopersicon esculentum*)	0.05	0	[73]
Walnut and English walnut (*Juglans regia*)	0	0	[26]
Watermelons	0.95	0.5	[74,75]

[1] 0.05 = little; 0.25 = modest; 0.65 = great; 0.95 = essential. Values introduced by Gallai and Vaissière [76] can be found in the tool on the website of FAO 's Global Action on Pollination Services for Sustainable Agriculture/Spreadsheet for assessing the value of pollination services and national vulnerabilities (http://www.fao.org/pollination/resources/pollination-assessment/economic-value/en/, (accessed on 2 January 2021)). [2] 0.2 = little, 0.5 = Modest, 0.7 = Great, and 0.9 = Essential. Values introduced for the needs of this study after literature review and empirical observations (notes/references) and assuming that honeybee colonies would be placed into pollinator-depended crops. *Nonavailable. ** Insect pollination is required only for seed production.

Furthermore, in the fourth methodological step, data were processed with the aid of the following formulae and the use of MS Excel software:

(A) Values per plant species

A1. Area = area covered with a certain cultivated crop or forest plant (ha)

A2. Utilization Rate = estimated use (100% for crops that provide pollen or nectar or both, or their pollination depend on honeybees and 0% for the rest of the agricultural and forest crops).

A3. Final Area = Utilization Rate × Area = A1 × A2

A4. Attractiveness = HB pollen (pollen supply) with values ranging from 0 to 2 and HB nectar (nectar supply) with values ranging from 0 to 2. For the agricultural crops of the study area, published US data were used pertaining to the same crops [26]. For forest species, the following values derived from empirical observations of local beekeepers were used:

- Deciduous bushes (Paliurus): HB Pollen: +2, HB Nectar: +2
- Oak: HB Pollen: 0, HB Nectar: +1
- Chestnut: HB Pollen: +2, HB Nectar: +1
- Pine: HB Pollen: 0, HB Nectar: +2

In all cases, values 0, +1, and +2 are in accordance with the following scale (USDA, 2017): "0" = not attractive, "+1" = attractive under certain conditions, and "+2" = highly attractive or exceptionally attractive.

(B) Calculations per local community

Attractiveness

B1. Total Attractiveness for each local community = Sum of (Final area × Attractiveness).

B1 = $\sum_{i=1}^{n} (A3i \cdot A4i)$, $i = 1, 2, \ldots$ n crops.

B2. Relative Attractiveness Index (RAI) = Total Attractiveness/Grand Total Attractiveness (for the 89 municipal units and local communities) (values from 0 to 1).

B2 = B1/$\sum_{j=1}^{89} B1j$, $j = 1, 2, \ldots$ 89 local communities.

Dependence

B3. Mean Dependence Ratio D = Dependence on pollinators (from 0 to 1) (Table 2).

B4. Potential participation of honeybees into pollination process P_{HB} (Table 2).

B5. Potential Dependence on Honeybee pollinators HBD = D × P_{HB}.

B5 = B3 × B4

B6. Total Dependence on HB pollinators for each local community = Sum of (Final Area × HBD).

B6 = $\sum_{i=1}^{n} (A3i \cdot HBDi)$, $i = 1, 2, \ldots$ n crops.

B7. Relative Dependence Index (RDI) = Total Dependence on HB pollinators/Grand Total Dependence (for the 89 municipal units and local communities) (values from 0 to 1).

B7 = B6/$\sum_{j=1}^{89} B6j$, $j = 1, 2, \ldots$ 89 local communities.

Priority

B8. Relative Priority Index (RPI) = Relative Attractiveness Index + Relative Dependence Index (B2 + B7).

B8 = B6 + B7

(C) Calculations per municipality

C1. Average Priority Index (RPI_A) per municipality = Average of RPI (B8) per municipality.

C2. Total Attractiveness Index (RAI_T) per municipality = Sum of RAI (B2) per municipality.

C3. Total Dependence Index (RDI_T) per municipality = Sum of RDI (B7) per municipality.

3. Results

3.1. Vegetation

Determining the suitability of rural areas can prove extremely useful in land use planning, as seemingly unrelated information can be organized into subsets of data capable of facilitating decision-making processes, in accordance with specific requirements. From the analysis of the areas with vegetation cover (A1 and A3) and taking into consideration the fact that the four examined forest species are of great beekeeping interest (utilization rate 100%), it appears that 83.34%, 93.70%, 76.44%, and 89.31% of the agricultural lands belonging to the municipalities of Almopia, Edessa, Pella, and Skydra, respectively, contain a total of 36 cultivated species that are of beekeeping interest (supply of pollen and/or nectar), of which 20 (Table 2) depend on the honeybees for their pollination.

3.2. RPI_A, RAI_T, and RDI_T Values and Heat Maps for the Research Area

Heat maps (Figures 1–3) illustrate in different hues of red the areas with great attractiveness (Map 1), the areas that are honeybee dependent for the pollination of their crops (Map 2), and the priority sites (Map 3) in the study area. A more detailed presentation per local community is made with the graded maps in Appendix A.

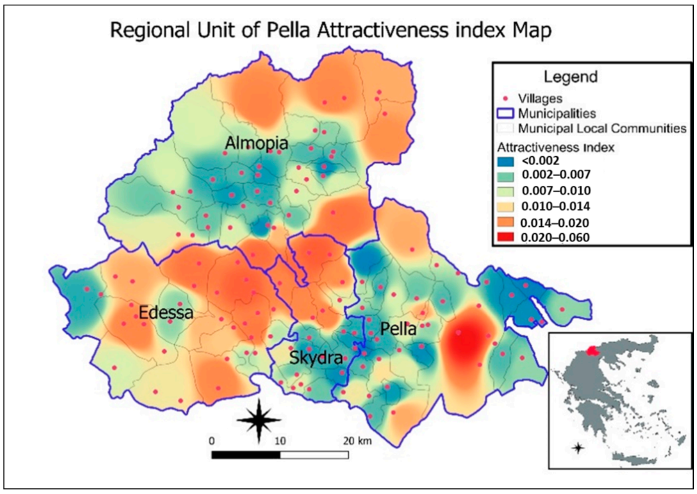

Figure 1. Relative Attractiveness Map (RAI) for year 2018.

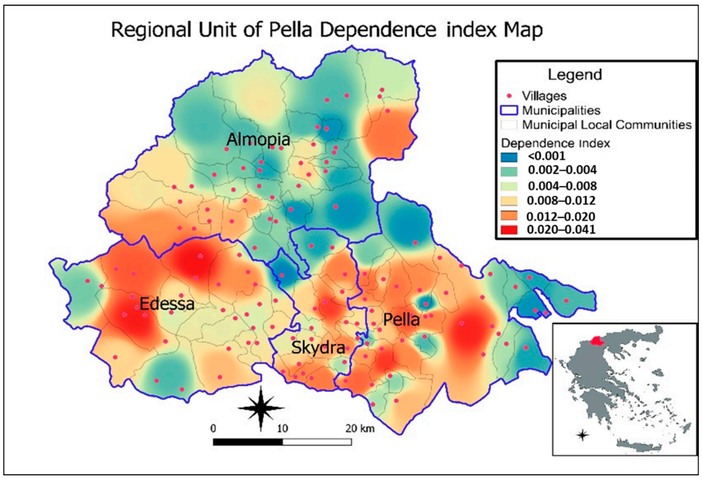

Figure 2. Relative Dependence Map (RDI) for year 2018.

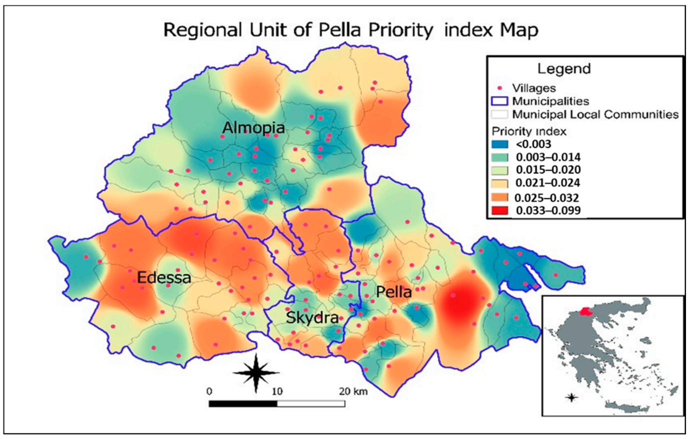

Figure 3. Relative Priority Map (RPIA) for year 2018.

Table 3 contains the Average Priority Index (RPIA) per municipality (C1) and the RAI_T (C2) and RDI_T (C3) values for the four municipalities:

Table 3. Relative Priority Index (RPI_A), Total Attractiveness Index (RAI_T), and Total Dependence Index (RDI_T) values.

Municipality	RPI_A	RAI_T	RDI_T
Edessa	0.0311	0.24	0.22
Skydra	0.0248	0.19	0.21
Pella	0.0221	0.26	0.36
Almopia	0.0176	0.32	0.21

The average value of the Relative Priority Indices (RPI_A) denotes the priority that can be given to each municipality, without taking into account the number of municipal units and local communities comprising it; instead, only dependence and attractiveness data are considered. Figure 4 depicts the 95% confidence intervals of RPI_As.

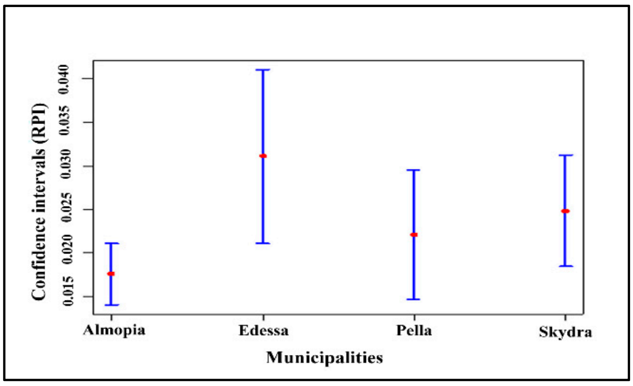

Figure 4. The 95% confidence intervals of RPIA.

Figure 5 shows the RPIA values per municipality in association with the areas occupied by all different crops and the four forests species. As can be seen, Priority Indices values calculated for the municipalities of Edessa and Skydra are at high levels in relation to the covered areas.

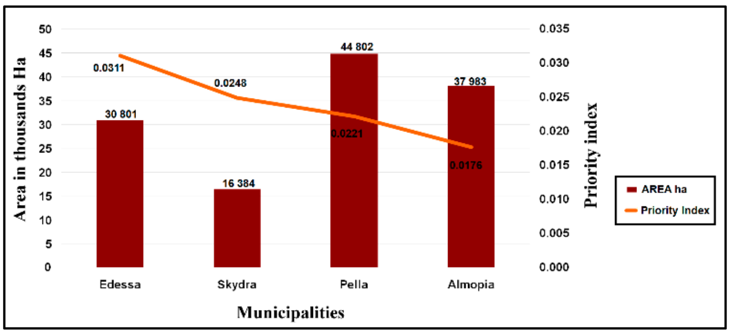

Figure 5. Values per municipality and Relative Priority Index (RPI_A) values.

4. Discussion

Determining the most suitable areas for the placement of beehives and their mapping is a very important task as it can reduce colony losses [77], while at the same time can ensure the pollination services in demand. Beekeeping ensures the sustainability and conservation of natural assets through the pollination of a great number of indigenous and cultivated plants. However, in recent decades, many agricultural practices have been designed in order to enhance crop production, but they have resulted in long-term pressures on the natural environment, thus affecting adversely indigenous pollinators and reducing pollination services. Apart from general governmental agricultural policy, local (municipalities) and regional (regional unit) authorities could adopt measures for apiculture development at a local scale. Similar environmental planning approaches are currently gaining more and more attention. For example, planners in Swedish Municipalities ask for the integration of general research into environment planning and the adoption of state-of-the-art scientific methods that could be put into practice. According to Palo et al. [78] "collaboration between stakeholders and researchers is needed which can create incentives, so that the decisions made by individuals, communities, corporations, and governments may be able to promote widely shared values compatible with Ecosystem Services."

The results of this study reveal that priority maps can be created based on the values of the Relative Priority Indices (RPI) for each local community to support decision-makers from local and regional authorities to adopt measures for apiculture development at a local scale. The results also point out that indicators vary at the municipality level according to the vegetative land cover and thus the interpretation of these indices must be done in combination and with great care.

More specifically: comparing the four municipalities (Figure 5), we can observe that the municipality of Edessa has the highest RPI_A value (0.0311) and the highest confidence interval for the average value, a fact that is due to the great variability among its municipal units and local communities. Figure 6 contains the values of the Total Attractiveness Index (RAI_T) in association with the corresponding areas. It can be seen that the Edessa Municipality presents increased levels of RAI_T ($\approx$0.24) in relation to the covered area. This finding is accounted for by the fact that the northern, northwestern, and eastern zones of this municipality contain the largest percentage of cherry orchards, other fruit trees, as well as chestnut and oak forests, which provide high amounts of pollen and nectar compared to the size of its covered area. It can be seen that the Edessa Municipality presents increased levels of RAI_T ($\approx$0.24) in relation to the covered area. This finding is accounted for by the fact that the northern, northwestern, and eastern zones of this municipality contain the largest percentage of cherry orchards, other fruit trees, as well as chestnut and oak forests, which provide high amounts of pollen and nectar compared to the size of its covered area. Besides that, the pollination of the covered area depends to a large extent on the honeybees owing to the fruit trees grown mainly in the northern and western zones; however, the value of the indicator is comparatively low in relation to the covered area due to the high percentage of forest species, which are mainly wind pollinated ($RDI_T \approx 0.22$, Figures 2 and 7). This means that as Edessa municipality, which contains crops with great beekeeping interest to a very high percentage (93.70% of agricultural land), as well as oak, chestnut, and *Pinus brutia* forests (20,574 ha out of 30,801 ha), can support honey production to a great extent, decisions must be made to improve honey collection conditions in combination with decisions to support the pollination of crops with honeybees (e.g., creation of specific beekeeping sites, utilization of forest areas, creation of communication networks between farmers and beekeepers, taking special measures for the protection of honeybees against pesticide application, etc.).

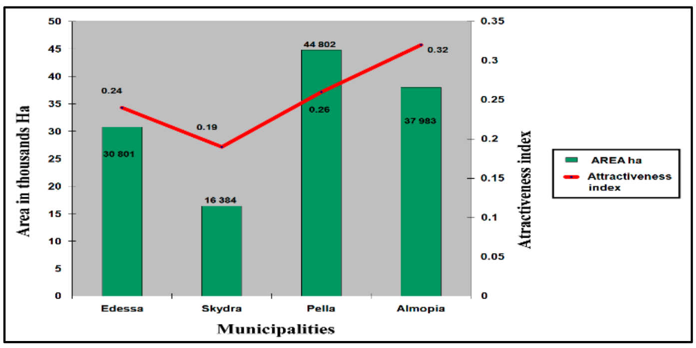

Figure 6. Covered areas and Total Attractiveness Index (RAI_T) values.

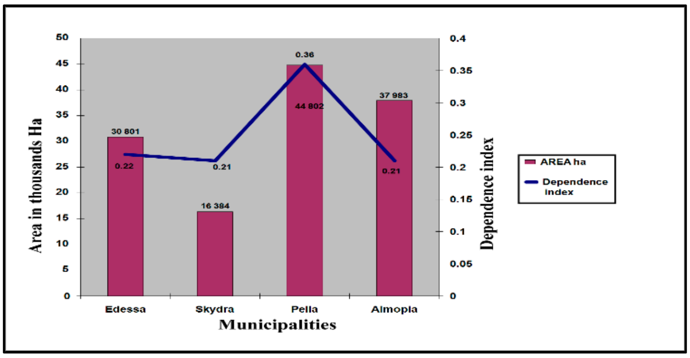

Figure 7. Covered areas and Total Dependence Index (RDI_T) values.

The Municipality of Skydra follows closely with a high RPI_A (0.0248) and a high confidence interval for the average value, a fact that is due to the equally great variability among its municipal units and local communities. In the central and southern zones of this municipality, the pollination of crops is to a large extent bee dependent (Figures 2 and 7, $RDI_T \approx 0.21$); moreover, the covered area provides significant amounts of pollen and nectar in relation to its size (Figures 1 and 6, $RAI_T \approx 0.19$) due to the presence of fruit trees in the central zone (89.31% of the agricultural lands) and the abundance of Paliurus shrubs (6660 ha from 7394 ha of forest areas) in the forest areas of the northern zone. The decisions to be taken should aim both at improving the conditions of honey production (road access and beekeeping sites) and supporting honeybee pollination.

In the municipality of Pella, RPI_A was found to be equal to 0.0221 with an equally high confidence interval for the average value. In this municipality, pollination is bee-dependent, in areas where fruit trees are cultivated (Figures 2 and 7, $RDI_T = 0.36$), but the covered area does not provide proportional amounts of pollen and nectar in relation to its size (Figures 1 and 6, $RAI_T = 0.26$) with the exception of the plain of Giannitsa, which combines crops of fruit trees and cotton. Therefore, the decisions to be taken in this municipality, which contains crops of beekeeping interest (76.44% of agricultural land), should aim at upgrading honeybee forages using public land for planting forest species of beekeeping interest and, secondarily, at supporting the pollination of crops by honeybees.

Finally, in the municipality of Almopia, in which the narrow confidence interval for the average value ($RPI_A = 0.0176$) is due to the low variability between the communities, RPI_A shows a very low value in proportion to the covered area (Figure 5). In this municipality, the covered area is attractive to honeybees mainly in the north-northeast zone owing to the presence of fruit trees (Figures 1 and 6, $RAI_T = 0.32$) and forest areas with oak, Paliurus, and, to a lesser extent, chestnut and *Pinus brutia* (19,502 ha from 37,983 ha). In terms of pollination, it is highly dependent on honeybees only in the southwestern zone and part of the northeastern zone (Figures 2 and 7, $RDI_T = 0.21$). Therefore, the decisions to be taken in this municipality should mainly aim at improving the conditions of honey collection (e.g., by increasing accessibility to honeybee forages, optimizing the placement of beehives, etc.).

In general, the targeted measures proposed for each municipality are expected to positively affect sustainable development in the entire Regional Unit, as beekeeping is a rapidly growing low-input agricultural activity [9,79] and a great number of the beekeeping structures are constructed by the beekeepers themselves. Dependence maps, which depict with varying intensity the dependence of entire areas on honeybees for pollination purposes, can constitute a powerful tool for raising awareness among both the public and the farmers about the value of honeybees in pollination, thus strengthening bee protection efforts undertaken globally. Additionally, the attractiveness maps that have been created in the frame of the current research provide a thorough picture of the areas that are food sources for bees at a local community level and, for this reason, they can serve as a general guide for the selection of areas with high potential for beekeeping and achieving high yields, regardless of other requirements, such as sunshine, proximity to water sources, hive competition, etc. [25].

5. Conclusions

For a higher land-use efficiency in land management, a comprehensive planning of land uses is required, which will take into account a wide range of technical, socio-economic, and political data. Additionally, the cooperation of planners and natural resource managers is of the outmost importance, as it is quite common that those who plan the allocation of natural resources do not happen to be their managers, too. Policies concerning land management should be further adapted to support apiculture. For example, although green direct payments (also called "greening") handed out to farmers under EU's Common Agricultural Policy (CAP) undoubtedly encourage them to adopt practices that preserve natural resources, they have failed to substantially prevent the loss of pollinator habitats and the decline in habitat quality. Agri-environmental measures also have poor contribution to this goal, mainly because they have not been implemented on a sufficient scale across the EU [80]. Moreover, biodiversity will be best conserved through a common agricultural policy if it is managed at landscape scales, thus facilitating collaboration among farmers to increase green patch size and landscape heterogeneity [81]. At national scale, the management of public land should also be reviewed. The national forest policy should be adapted to facilitate the exercise of beekeeping activities in the forests [79]. In many areas, as, e.g., in the Greek countryside, beehives are placed almost freely (with only some restrictions concerning distances from roads etc.) in public land (grasslands and forests) according to national legislation (Law 4856/1930; Law 6238/1934) but without any guidance from local authorities. In a different approach, in Victoria, Australia, the Department of Environment, Land, Water and Planning is responsible for public land apiary sites management and public land apiculture policy, according to rules and procedures that are predefined in detail [82]. Nevertheless, local and regional decision-making authorities have the potential, through small-scale interventions, to contribute to the preservation of the environment and the local agricultural economy.

Over the last two decades, Greek legislation has given increased authority to the municipalities, which, in recent years, through their organized services, pursue agricultural and environmental policy goals at a local level. Adopting measures focusing on optimal land use, supporting bee pollination, honey collection, or a combination of all these targets is expected to enhance apiculture development at a local scale. At the Regional Unit level, environmental planners can first take the RPI_A indicator into consideration prior to selecting priority areas. Priority will be given to the municipality with the highest RPI_A value. Decisions should be taken after cross-examining the overall Attractiveness Index (RAI_T) and Dependence Index (RDI_T). Increased levels of RDI_T in proportion to the corresponding area means that decisions must be directed towards supporting bee pollination. Increased RAI_T values in proportion to the corresponding area means that decisions must focus on improving honey collection conditions.

The main disadvantage of the proposed method is that the proposed indicators have only relative value since they are derived based on the data of a local Regional Unit where specific crops and forest species grow. However, these indicators could be adapted and implemented in other regional units and especially in municipalities with similar characteristics. Another disadvantage is that the evaluation criteria of the municipal units and local communities did not include considerations such as the flowering time range; the supply of pollen and nectar from native plants (e.g., *Trifolium repens*, *Asphodelus ramosus*, *Cistus incanus*); and the type, quality, and unit prices of the honey produced. Furthermore, factors such as "pollen supply" and "nectar supply" have a limited range (0–2) and are not in all cases true, since a plethora of other key-factors (rain, heat waves, drought, wind, sunshine, insects, etc.) affects the result, and this effect is common in forest species. Finally, the level of dependence of pollination on honeybees, is not specifically adapted to the study area, but it was derived from literature review process, to serve the needs of the current research paper. In fact, this approach lacks in accuracy, but as the number of experimental studies that directly calculate dependence factors is extremely low, even with regard to the most important products in terms of pollination needs and world value [83], it helps achieve the goal of developing a methodology that will ultimately assist decision-makers to take specific measures for apiculture development. In order for previous obstacles to be overcome, future research should focus through properly designed and organized experiments on clarifying the role of the bee as a pollinator under usual cultivation conditions prevalent in Greece, on depicting beekeeping vegetation in digital maps and on data processing via geographic information systems.

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Appendix A

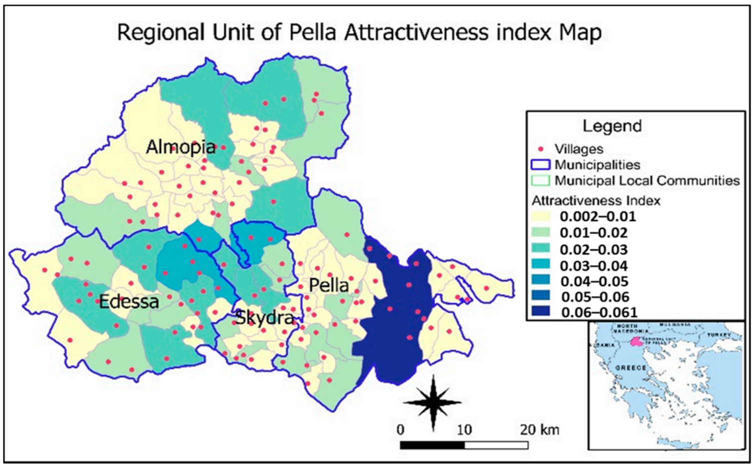

Figure A1. Graded Attractiveness Map (RAI).

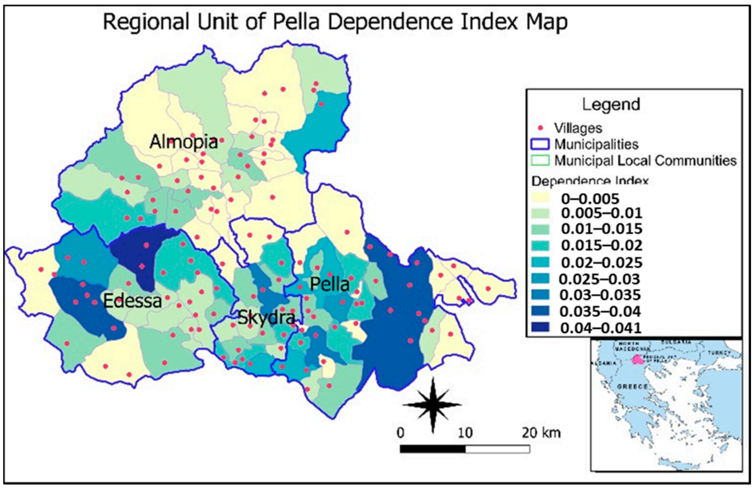

Figure A2. Graded Dependence Map (RDI).

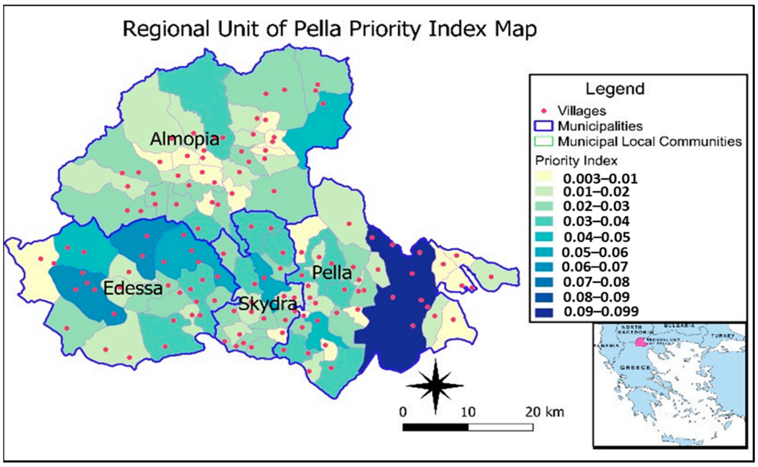

Figure A3. Graded Priority Map (RPI).

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