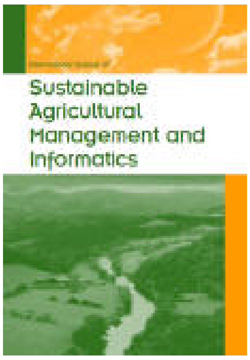

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Abstract: In this study, the effect of the forest road network to the spatial organisation and management of nomadic beekeeping is investigated. The study was performed in conditions of Greece. For the selection of suitable apiary sites for hive placement, we have used internationally accepted criteria in compliance with the legal requirements regulating apiary siting. After the eligible area for hives placement was calculated and mapped, we examined how the scenario of constructing new forest roads may affect the exploitation of the research area covered with Paliurus shrubs. From the results of this study can be concluded that new roads can improve the spatial distribution of apiaries, a fact that is expected to result in high yields and profitability.

Moreover, the authors propose, in parallel with the planning of new roads, the construction of apiary sites with enrichment bee flora, which will ultimately evolve into well managed bee parks. As there are no similar studies concerning the direct effect of forest roads in beekeeping activities, future studies should support specific developing plans by conducting a cost-benefit analysis.

Keywords: forest road network; beekeeping; spatial organisation of apiary sites; apiculture development.

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1 Introduction

Greek apiculture is a growing branch of primary production, as evidenced by the large number of beekeepers [amounting to a total of 24,582 beekeepers in the period 2017–2019 (European Commission Agriculture & Rural Development, 2020)] and the significant distinctions and awards received by Greek honey brands in international competitions. There are approximately 1.5 million hives and honey production in Greece ranges from 15 to 20 thousand tons (European Commission Agriculture & Rural Development, 2021). Average honey production ranges from 15 to 20 kg/hive; with a density of 10 hives/km^2 and 147 hives/beekeeper, Greece ranks first in hive density and number of hives per beekeeper compared to the rest of the European countries (European Commission Agriculture & Rural Development, 2021; European Commission DG, Agriculture and Rural Development, 2013).

Honeybee is an insect at the interface between human and ecosystem health that provide regulating, and cultural services (Papa et al., 2022). Nomadic or migratory beekeeping is a practice widespread in Europe that beekeepers move their beehives in specific seasons and places in order to obtain specific types of honey that are linked to certain plants, and at the same time, increases the yield (Pignagnoli et al., 2021). The migratory beekeeper schedule viable visits in bee-forage sites and calculates their profitability levels (Pilati and Prestamburgo, 2016). Given that Greek beekeeping is conducted in a nomadic manner, the ability to place honeybee colonies in forest areas during nectar production and secretion depends on the presence of beehive placement positions and their accessibility by beekeepers. Sites of hive placement must away from the roads and far from residential areas. The number of colonies and the distance between apiaries depended on nectar production dynamics of the native melliferous flora (Albayrak et al., 2021). Moreover, beekeeping sites must provide sufficient space, be easily accessible and not covered by forest vegetation and rocks. Greek Law 6238/1934 (Government Gazette 265 A) allows placing apiaries in uncultivated or forested areas belonging to the state, or to municipalities, municipal communities, monasteries, or legal entities, without the imposition of any kind of fee or rent for a maximum of three months; for longer-term placements a rent is required. Beehive placement is permitted at a distance of 25 m from public roads. The free establishment of apiaries in forests is still allowed for by Law No. 4856/1930 (Government Gazette 316 A), according to which all public and municipal areas may be characterised as potential 'bee parks' in the sense that interested beekeepers are free to place their hives on condition that they meet the necessary fire safety requirements as stipulated by forest legislation (Hellenic Ministry of Rural Development and Food, 2010).

However, the results of a survey conducted in the Regional Unit of Pella, Greece, reveal that the lack of space for hive placement is considered a serious problem by 62.7% of the respondents. Reduced accessibility to convenient beehive locations is often attributed to the absence of a suitable road network (Marnasidis et al., 2021a). Increased beehive density can also have a significant impact on bee behaviour and facilitate the transmission of diseases and pests between colonies (Sobkowich et al., 2021). According to Al-Ghamdi et al. (2016), the concentration of a large number of hives in limited areas is an important factor that adversely affects yields, as overcrowding, in excess of the colony carrying capacity, leads to the depletion of bee forage resources. A minimum forage distance of 1.0 km between apiaries is estimated to help prevent resource competition and maximise honey productivity per hive.

Marnasidis et al. (2021b) report the criteria used as well as the methodology implemented in recent research for identifying areas suitable for beekeeping activities. The list includes: landscape quality within 1.5 km from the hives, vegetation composition, attractiveness, flowering seasons, temperature, rainfall, access via road networks, available water resources, altitude, land uses, and monthly pollen and nectar supplies. Sarı et al. (2020) presented the implementation models of beekeeping suitability analysis, including the criteria of each model. Sari (2022) generated forest fire risk index and flood hazard risk index by considering the criteria and their relative weights that have an effect on both forest fire and flood hazard in the field of topographic, environmental, climatic and economic factors. Forest roads constitute a key success factor for all productive activities taking place in forests (Yildirim and Kadi, 2020). The existence of a suitable road network is a prerequisite for assessing and determining whether specific areas are suitable for beekeeping, according to studies by Abou-Shaara et al. (2013), Amiri and Shariff (2012), Sari (2022), Sarı et al. (2020) and Zoccali et al. (2017). It is imperative that forest roads are in good condition and functionality. The main reasons leading to road pavement faults and failures include weather conditions and road use. Rainfall and snow tend to cause erosion, and coupled with the frequent use of roads by heavy vehicles, may result in serious damage to road pavements. This makes roads non-functional to such an extent that their maintenance and reuse is economically difficult or unfeasible.

The construction and thorough maintenance of an efficient forest road network is of paramount importance, because only in this way can the desired access to the forest (Picchio et al., 2018a; Akay et al., 2021; Dudáková et al., 2022) and its precious resources be achieved (Boston, 2016); besides, they constitute an integral part of sustainable forest management (Kazama et al., 2021). Such networks provide forest protection as they play a crucial role in helping extinguish forest fires (Laschi et al., 2019) and therefore are of the utmost importance in the protection of the environment (Parsakhoo et al., 2010; Parsakhoo and Jajouzadeh, 2016). Forest roads are one of the most essential structures that facilitate a wide array of activities, such as timber harvesting (Akay et al., 2020), transportation of forest biomass (Bitir et al., 2022) and agricultural residues for biogas production (Kantartzis et al., 2021), as well as hunting (Mathisen et al., 2018). They also serve commercial and recreational purposes (Picchio et al., 2018b). According to Laschi et al. (2016), all forest activities are enhanced when the forest road network is efficiently designed. By the same token, in areas where there is no road network, construction of new roads is bound to promote reforestation and economic growth (Kaczan, 2020). Ioannou et al. (2010) have developed software that, once applied in practice, will substantially contribute to the evaluation of forest roads, and in particular, will strengthen their positive impacts on forest holdings and rangelands, transport conditions, the labour market, and the national economy.

The current study investigates the contribution of the forest road network to the spatial organisation of nomadic beekeeping, so that hive overcrowding may be avoided and higher yields could be achieved. It also examines the potential of expanding the road network in areas of limited access from the usual beekeeping vehicles, with the aim of optimising the spatial distribution of apiaries for the complete exploitation of areas with melliferous plants (pollen and nectar rich species). As research area we selected the Edessa Municipal Community, located in the Regional Unit of Pella, Greece, and as melliferous plant the forest species Paliurus (*Paliurus spina-christi Miller*).

2 Research area

The research area includes the Edessa Municipal Community (Figure 1), which consists of the city of Edessa as well as villages Ekklisohori, Kaisariana and Proastio. The city of Edessa, with a population of 19,036 inhabitants according to the 2011 census, is the capital of the Regional Unit of Pella.

The economy and growth of the city are mainly based on the tertiary sector (public services and tourism). As far as beekeeping is concerned, it is a branch of primary production that, despite its very small size in relation to agriculture, has been growing at a steady pace over the last decade. Reliable statistical data on local beekeeping is available at the municipal level. These datasets also show the trend that the studied area showed. According to the aggregate data of the last decade (2012–2020) issued by the Greek Payment Authority of Common Agricultural Policy Aid Schemes, the Municipality of Edessa witnesses a gradual increase in the number of beehives (Table 1 and Figure 2) kept in the area.

Figure 1 Research area (see online version for colours)

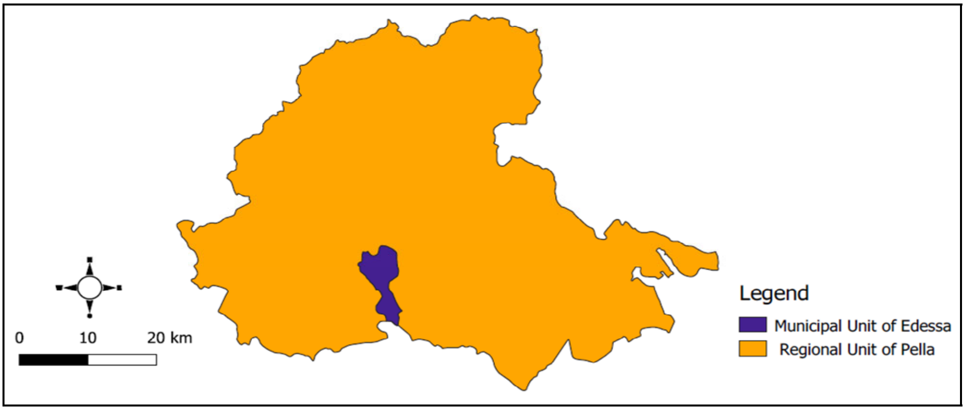
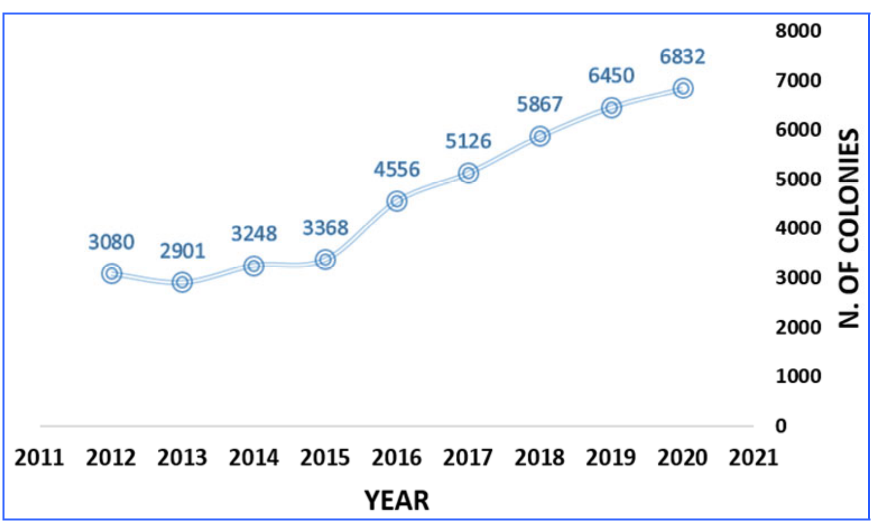


Table 1 Number of beehives in the Municipality of Edessa in 2021–2020

Year	*Number of hives*
2012	3,080
2013	2,901
2014	3,248
2015	3,368
2016	4,556
2017	5,126
2018	5,867
2019	6,450
2020	6,832

Figure 2 Evolution of the number of hives in the Municipality of Edessa, 2012–2020 (see online version for colours)



The bee flora of the area includes the following cultivated and forest species, according to data from the Pella Directorate of Agricultural Economy and Veterinary Services and the Forest Service of Edessa (Table 2).

Table 2 Bee flora of the research area

Bee flora class	*Plant name*	*Total area (ha)*	*Flowering season – nectar producing period*	
Fruit trees	Almonds (*Prunus amygdalus*)	2.71 ha	20-Feb.	20-Mar.
-//-	Plums (*Prunus domestica*, *Prunus salicina*, *Prunus Americana*)	11.87 ha	25-Feb.	15-Mar.
-//-	Nectarines (*Prunus persica nectarina*)	17.43 ha	28-Feb.	20-Mar.
-//-	Peaces (*Prunus persica*)	50.6 ha	28-Feb.	20-Mar.
	Apricots (*Prunus armeniaca*)	17.6 ha	1-Mar.	25-Mar.
-//-	Sweet cherries (*Prunus avium*)	189.3 ha	21-Mar.	12-Apr.
-//-	Apples (*Malus domestica*)	3.97 ha	6-Apr.	30-Apr.
-//-	Kiwi fruits (*Actinidia deliciosa*)	10.3 ha	8-May	16-May
Deciduous shrubs	Paliurus (*Paliurus spina-christi*)	999.88 ha	15-May	10-Jun.
Forest	Oak (*Quercus spp.*)	965.708 ha	01-Jul.	30-Jul.
Forest	Pine (*Pinus brutia*)	129.00 ha	01-Aug.	05-Sep.
			20-Sep.	01-Nov.

3 Methodology

In order to achieve the aim of the study, we collected, processed, and analysed spatial information concerning the forest areas. For the delineation of the area studied, the administrative boundaries of the country's prefectures, municipalities, and municipal communities were used as specified in accordance with the recently introduced 'Kallikratis' local government system. The data were retrieved in Shapefile format [a data format for Geographic Information System (GIS) software] and processed in QGIS 3.22.6 (https://www.qgis.org/en/site/).

A prior research project (Marnasidis et al., 2021b) verified the data provided by the Hellenic Ministry of Environment and Energy (http://mapsportal.ypen.gr/layers/geonode:ken_mak_tel), concerning spatial information on land cover with vegetation type 'deciduous shrubs' (Paliurus). The same spatial data were also used in the present research paper.

In this study, to facilitate hive transportation vehicles, the minimum area size for hive placement has been set at 0.02 ha. With the help of QGIS software, areas dominated by Paliurus with size less than 200 square metres were excluded from the selected sites for hive placement. Slope of the locations and density of the studied vegetation were also key criteria for selecting apiary sites (Sarı et al., 2020). Maximum slope value for an ascending C-class forest road is set at 12%. The selected areas in this study are those whose slope does not exceed 10%.

A digital elevation model (DEM) was also produced to provide slope relief data based on 1:5,000 scale maps issued by the Hellenic Military Geographical Service.

Subsequently, with field observations carried out in various Paliurus-dominated areas, we specified the densities to be considered in order to calculate the number of hives that can be placed in forest lands, depending on the prevalent vegetation and terrain relief conditions. Eligible apiary sites were classified and digitised in three groups based on density classes:

- 1st group: Sites with thin canopy cover, ranging from 0 to 20%, with maximum siting capacity of 200 hives/ha, as their soil tends to be stony with harsh morphology, and the scarce vegetation restricts the movement of both people and vehicles.
- 2nd group: Sites with moderate canopy cover, ranging between 21 and 60%: in this case, the capacity cannot be calculated because numerous intervention projects are needed (such as Earth works and layout redesigning).
- 3rd group: Sites with dense canopy, in excess of 60%, where there is total inability for apiary siting.

Due to the various problems encountered with hive placements in pastures, beekeepers establish their apiaries in the vicinity of rural or forest roads, apparently ignoring the relevant legislation that is in force (Figure 3).

Figure 3 Apiary siting in research area (see online version for colours)

Another issue that emerged during field observations from our research team is that the condition of the road network is considered sufficient; however, regular maintenance should be carried out in order for accessibility to be sustained throughout the year.

Proximity to the official hydrographic network was not used as a criterion of site exclusion, as the research area includes a wide diversity of water resources that are sufficient enough to meet the needs of bees, such as natural springs, the irrigation network of open cement canals operated by the local land reclamation organisation, drainage networks of the irrigated fields, etc. In addition, beekeepers can create watering stations for the water needs of their colonies in areas where there is a proven water shortage or when their apiaries are in the vicinity of residences, hotels, etc. so as to avoid causing disturbance.

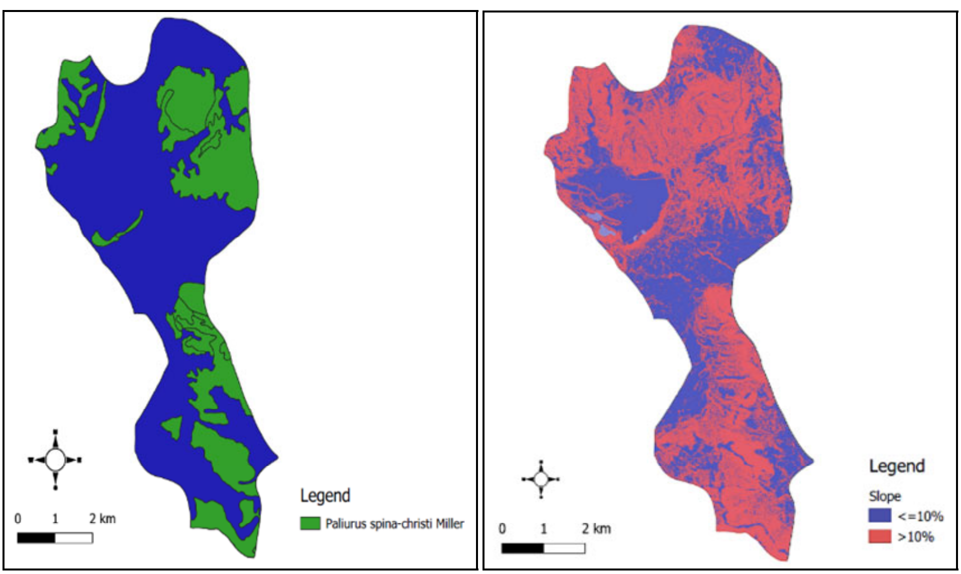
The next criterion to be set was distance from public roads. According to this criterion, all kinds of public forest or agrarian roads were excluded from the research as well as the areas located at a distance of more than 25 m on either side of them. The term 'public roads' refers to all types of roads that serve the movement of passenger and agricultural vehicles. The existing municipal and agricultural road network was digitised with the help of QGIS software, incorporating all restrictions imposed by the legislation as to the distance that should exist between apiary sites and road networks. Through this procedure, we finalised the sites that comply with the legislation, namely those located at a distance of less 25 m from public roads.

We do not calculate the weights of the selected criteria among the factors that affect the total suitability for hive placement, because we consider that all criteria affect equally, the ability of this beekeeping activity.

4 Results

Figure 4(a) depicts the administrative boundaries of the Edessa Municipal Community; in green are the Paliurus-dominated sites, which occupy a total area of 999.88 ha (Table 2).

Figure 4 (a) Paliurus-dominated sites (B) Slope mapping in Edessa Municipal Community (see online version for colours)

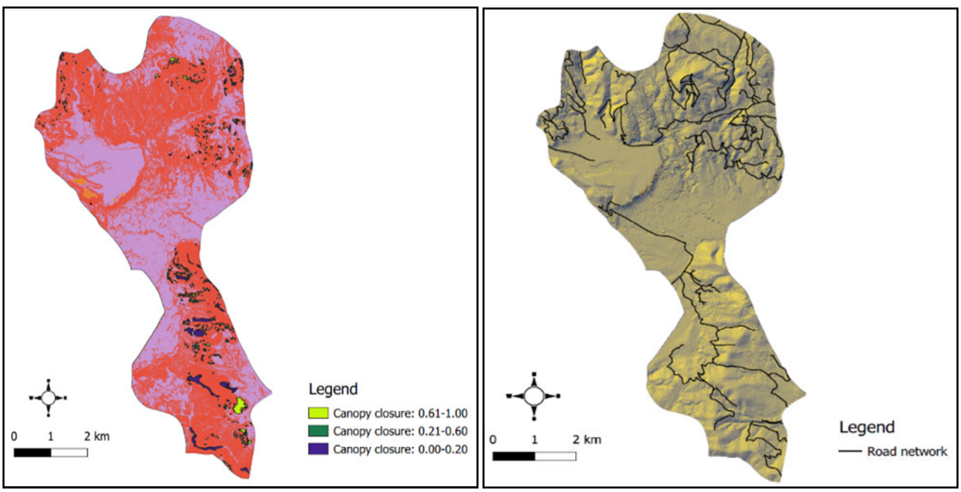


(a) (b)

In order to determine which areas satisfy the slope criterion, two slope classes were created. The map in Figure 4(b) illustrates the areas whose slope ranges between 0 and 10% (eligible areas) and those whose slope is over 10% (ineligible areas). The technical features of the road network are in accordance with the technical specifications that correspond to C-class country, forest and agrarian roads. Forest roads, in particular, are approx. 5–6 metres wide, their slope ranges from 7% to 9%, and they are accessible to any type of vehicle that serves the needs of hive transport. Apparently, if the density of the road network was higher, it would be easier for the available areas to be used as apiary sites.

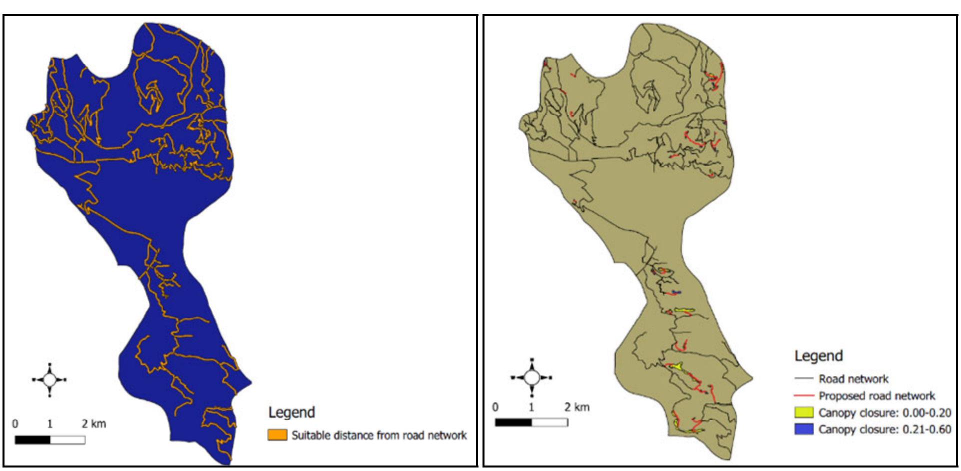
Subsequently, the eligible areas were classified and digitised in three classes based on the density groups. The densities map of the Paliurus-dominated forest areas depicts in dark green and purple the eligible apiary sites [Figure 5(a)], after applying the aforementioned ‘slope’ and ‘minimum area size’ criteria.

Figure 5 (a) Map of vegetation densities and (b) map of existing road network in the Edessa Municipal Community (see online version for colours)



(a) (b)

Figure 6 (a) Map of existing road network according to the ‘distance from public road’ criterion and (b) layout of a new proposed road network (see online version for colours)



(a) (b)

The total area occupied by sites whose vegetation density is equal to 0%–20% was estimated at 40.75 ha. The existing municipal and rural road network was afterwards digitised with the help of QGIS software [Figure 5(b)].

The restrictions imposed by the law regarding the distance that must exist between apiary sites and the road network were applied as follows: distance from public road > 25 m: eligible site; distance ≤ 25 m: ineligible site. Through this procedure, the sites complying with the legislation, or, in other words, sites with more than 25 m distance from public roads [Figure 6(a)], were selected. The areas that meet all eligibility criteria and also have access to the road network occupy a total area of 17.35 ha.

If new forest roads with a total length of 8.16 km [Figure 6(b)] are opened up and constructed, they will provide accessibility to new apiary sites whose total area will be 6.05 ha. The areas that meet all eligibility criteria and also have road access will occupy, after the construction of the proposed new network, a total area of 23.4 ha.

5 Discussion

The aim of the present research was to assess the effect of a well-designed and maintained forest road network to the spatial organisation and management of nomadic beekeeping. To achieve this goal, we investigated the possibility of placing hives in positions that meet the specific eligibility criteria set, for increasing the exploitation of the research area covered with Paliurus shrubs. In order to determine the optimal colony carrying capacity of the area under investigation, the following assumptions were made:

a Honey consumed by colonies for their energy needs: according to Al-Ghamdi et al. (2016), in Europe, a normal-sized colony consumes about 60–202 kg of honey per year in order to meet its energy needs as well as for brood rearing. A large and healthy colony produces 60 to 200 kg of honey per year. Based on this rough estimate and assuming that all factors remain constant, 2 kg of honey will be required in order to harvest 1 kg of honey.

b Literature review on honey production from *Paliurus spina-christi*:

 b1 According to the results of a research project carried out by Hasilidis et al. (2011) at the western feet of the Paiko Mountain, Regional Unit of Pella, Greece, from 20 May to 10 June, in a 13,370-ha sized area, of which 11,150.58 ha (83.4%) were productively used (flight radius: 1,500 m), the number of Langstroth hives amounted to 11,462 (~ 1 colony/ha), which yielded approximately 100,000 kg of monofloral Paliurus honey. It appears that an average harvest that also covers the colony's needs is equal to (100,000 × 2) kg / 11,150.58 ha = 17.93 kg/ha or 200,000 kg / 11,462 colonies = 17.45 kg/colony. An average yield of 10 kg/colony has been long considered by the beekeepers of the region as a satisfactory yield of fully productive colonies, and therefore, honey collection must reach 20 kg/colony.

b2 The quantities of honey that various plants can theoretically produce, together with data collected from various literature sources, based on research carried out both in Italy and in various Eastern European countries, are presented by the Scuola Di Agricoltura Sostenibille (2020). Due to the changeability in nectar secretion as a result of various geoclimatic factors, Paliurus (*Marruca Paliurus spina-christi Rhamnaceae*) yields in Italy amount to 400 kg/ha, a quantity that outweighs by far the 17.93 kg/ha yield which we calculated for the studied area based on the data by Hasilidis et al. (2011). This difference may be attributed to factors such as the climatic and soil conditions prevalent in the Greek research area and the large concentration of hives in the Paiko Mountain (40% of colonies correspond to 21.1% of the studied area).

c Estimated colony carrying capacity of the area under investigation: Based on the data presented so far, if we assume that a harvest of 10 kg/colony, and therefore a collected quantity equal to 10 × 2 = 20 kg/colony would be desirable and satisfactory to the beekeeper and sufficient for the needs of the colony, carrying capacity is calculated as follows based on data from Hasilidis et al. (2011): 17.93 kg/ha × 999.88 ha = 17,927 kg which means 896 colonies / 999.88 ha ~ 0.9 colonies/ha or 90 hives/km^2. Based on the data from the Scuola Di Agricoltura Sostenibille (2020): 400 kg/ha × 999.88 ha = 399.952 kg which means 19.998 colonies / 999.88 ha ~ 20 colonies/ha or 2,000 hives/km^2.

Our field observations showed that pastures whose Paliurus cover ranges from 0% to 20% have a siting capacity of up to 200 hives/ha. The total area of the selected apiary sites, after applying the spatial arrangement criteria analysed in Section 3, was estimated at 17.35 ha, which means that the siting capacity amounts to 17.35 ha × 200 hives/ha = 3,470 hives. Therefore, we can estimate the density as 3,470 colonies / 999.88 ha = 3.47 colonies/ha = 347 hives/km^2.

From the results of the current study, it becomes clear that constructing new forest roads with a total length of 8.16 km [Figure 6(b)] may provide access to new apiary sites whose total area amounts to 6.05 ha, which means that the additional siting capacity will amount to 6.05 ha × 200 hives/ha = 1,210 hives. Therefore, the new siting capacity is calculated at 3,470 + 1,210 = 4,680 hives and the new density is 4.68 hives/ha. This shows a significant improvement in the exploitation of honey produced by Paliurus shrubs.

6 Conclusions

From the results of this study can be concluded that an extensive road network improves the spatial distribution of apiaries and allows beekeepers to access multiple apiary sites for hive placement, a fact that is expected to result in high yields and profitability.

Nevertheless, it remains doubtful the number of hives that beekeepers can place in public forest lands. As an optimal solution, the authors propose, in parallel with the planning of new roads, the construction of apiary sites with enrichment bee flora, which will ultimately evolve into well managed bee parks. These sites must be equipped with all the necessary infrastructure that will facilitate all beekeeping activities, such as inspections, harvesting, royal jelly collection, etc.

As there are no similar studies concerning the effect of forest roads in beekeeping activities, future studies should support specific developing plans for beekeeping activities by conducting a cost-benefit analysis.

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