The vulnerability of Mediterranean beekeeping to climate change

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Research Article

Keywords: adaptation, pollination, global environmental change, agroecology, honeybees

Posted Date: August 23rd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1893472/v1

Abstract

Beekeeping is being impacted by climate change in the Mediterranean region. Examining the vulnerability of beekeeping to climate change is highly relevant not only due to the pollination services that honeybees provide; but also in terms of food security. To provide a comprehensive overview of the vulnerability of beekeeping to climate change, here we examined the exposure of beekeeping to climate drivers and the adaptation strategies undertaken by beekeepers in Mediterranean Spain. In doing so, we reviewed the scientific literature and performed focus groups with experts to identify the main drivers occurring and afterwards assess the beekeepers' perceptions. The study discloses the complex nature of the vulnerability of Mediterranean beekeeping, with climate change being a contributing driver. While the specialized literature tends to highlight the spread of diseases, the spread of species hostile to honeybees, habitat loss and fragmentation, intoxication by both pesticides and acaricides, the colony collapse disorder, as well as climate change. The results of this work point that the transformations occurring within the socio-economic and policy domains tend to be dismissed. Results also point that the vulnerability of honeybees and beekeeping is not only characterized by the existence of multiple transformations, but also by the huge and diverse adaptation capacity of beekeepers. Diversification, Mobility, Intensification, Agroecology and Cooperation are the main groups of adaptation strategies identified. Finally, we also found that honeybee operations of different size rely on different adaptation strategies. This is highly relevant in terms of policymaking, since policy makers need to consider this diversity of farming practices when developing appropriate climate policies.

1. Introduction

Beekeeping has been conducted all over the world for millennia (Roffet-Salque *et al.* 2015). There is large consensus in pointing both its socioeconomic relevance as well as the fundamental services it provides through pollination. However, sudden losses of large numbers of honeybees in the early 2000s, mainly in the United States and Europe (Hendrikx *et al.* 2009; Pizarro and Montenegro 2012), and new knowledge about their role in biodiversity conservation (Balvanera *et al.* 2005; Kremen 2005) and food security (Millennium Ecosystem Assessment 2005; Aizen and Harder 2009; Gallai *et al.* 2009; Lautenbach *et al.*, 2012; Klatt *et al.* 2014) have contributed to change our views of honeybees. There is still a lack of knowledge about the vulnerability of honeybees and beekeeping to global environmental change, and in particular to climate change. In addition, there is a lack of knowledge about how these transformations are affecting the honeybee farms of different sizes. This is particularly relevant in view of the widely polarized nature of the sector, where professional operations are getting larger and small, non-professional beekeepers still remain very relevant (Chauzat et al., 2013). Thus, in this article, through a literature review and interviews to experts and beekeepers, we examine (i) the main elements involved in the vulnerability of honeybees and beekeepers to global environmental change in Mediterranean Spain; (ii) the main transformations beekeeping is undergoing in the area; and finally (iii) the diverse strategies followed by beekeepers to deal with or benefit from these transformations.

1.1. Beekeeping as an economic activity

Beekeeping has a very important economic weight within European agriculture. There are approximately 631,000 beekeepers in Europe, 97% of whom are not professionals and account for 67% of the hives – that is, those with less than 150 hives. Germany and France, with 98,000 and 75,000 respectively, are the countries with the most beekeepers. European honey production, with 204,000 tons (European Commission 2015), accounts for 12.4% of world production. Beekeeping importance has been increasing both in terms of honey production - from 310 tons in 2001 to 372 tons in 2014 – and in number of beekeepers in global terms - from 470,797 in 2003 to 631,236 in 2014. Spain, with 28,786 beekeepers and almost 3 million hives in 2018 has the most hives out of any country in Europe and the highest degree of beekeeping professionalization. While the average amount of hives per professional beekeeper is 386, in the case of non-professional beekeepers is 33. The percentage of professional beekeepers is 23% (2018), and both professional and non-professional beekeepers are on the rise in the last years. In particular, beekeeping in the Spanish Mediterranean region comprises one-third of Spanish beekeepers, 42% of hives and half of the honey production of the country (MAPA 2021). Yet, it is important to clarify that different management strategies exist, drawing a complex picture of beekeeping as a heterogeneous activity, very often linked to the size of the farm, but not only. In that sense we can find more extensive farming systems of honeybees that are usually smaller, have a lower population in the hives and have a strong focus on the welfare of the honeybees. On the other side we can find more intensive farming systems, with a bigger amount of hives which are also more populated.

1.2. Beekeeping as a major provider of ecosystem services

Beekeeping provides of fundamental ecosystem services thanks to honeybee's nature as pollinator (Balvanera *et al.* 2005; Kremen 2005). It is largely assumed that pollination entails a fundamental link to present and future food security. In fact, it is estimated that between 60 and 90% of wild plants (Kearns *et al.* 1998; IPBES 2016) and 70% of the world's most common crops - accounting for 35% of food production and including vegetables, fruits and crops such as rice, wheat, corn or potatoes - depend on animal pollination (Ashman *et al.* 2004; Klein *et al.* 2007). In the European Union, production of about 80% of the species grown is directly dependent on insect pollination, and especially on honeybees (Williams 1994). In particular, the contribution of honeybees to the provision of the pollination services is notable. It is estimated that out of the 100 crops that provide 90% of world's food, 71 depend on honeybee pollination (FAO 2010).

Several studies have attempted to calculate the economic value of pollination as a global ecological service. Constanza et al. (1997) estimated it to be 88,000 million euros. More recently, Gallai *et al.* (2009) increased this figure up to 115,000 million, equivalent to 9.5% of the value of global food production. Additionally, we must also bear in mind that the volume of agricultural production dependent on animal pollination has increased by 300% in the past 50 years, but pollinator-dependent produces show inferior growth and stability in yield than crops that do not depend on pollinators (IPBES, 2016). Considering the comparative increase in importance of pollinator-dependent crops, Lautenbach *et al.* (2012) estimated the value of pollination at 265,000 million euros. Specifically, the contribution to the value of pollination generated by honeybees is also notable. In Europe it is estimated that honeybees annually contribute

22,000 million euros to European agriculture (European Commission 2013). Their contribution is even more outstanding in the Mediterranean countries - in Spain it varies between 4,000 and 24,000 euros per square kilometer of cultivated land (REFERENCE).

1.3. Drivers of change of beekeeping

Despite the number of hives has increased by about 45% in the last 50 years worldwide (Aizen and Harder, 2009); different regions present distinctive trends. For instance, Europe (-26.5%) and North America (-49.5%) experienced notable declines between 1961 and 2007, while the trends in Asia (426%), Africa (130%), South America (86%) and Oceania (39%) were radically the opposite (FAO 2009). In particular, Spain has experienced a constant growth since the 1970s, with a tendency to stabilize from 2003 on. However, the growing number of hives should not hide the rising mortality being reported among honeybees (Chauzat et al., 2013).

There is also increasing evidence of a sharp decline in the diversity of wild bee species and insect-pollinated plants (Steffan-Dewenter *et al.* 2005; Biesmeijer *et al.* 2006). The specialized literature points to diverse global environmental change transformations behind this decline (Potts *et al.* 2010; González-Varo *et al.* 2013; Henry *et al.* 2012). But the consensus is low on the specific causes (Goulson *et al.* 2015) since pollinator declines are not universally observed beyond anthropogenic ecosystems (Herrera 2018). Thus, several are the trends and changes mentioned, being climate change one of them (Memmott *et al.* 2007; Hegland *et al.* 2009): (i) spread of diseases (Cameron *et al.* 2011); (ii) spread of invasive non-native species (Moron *et al.* 2009); (iii) habitat loss and fragmentation (Garibaldi *et al.* 2011); and (iv) intoxication, mainly coming from industrial agriculture (Kremen *et al.* 2002; Tscharntke *et al.* 2005; Gill *et al.* 2012; Whitehorn *et al.* 2012; Goulson *et al.* 2018).

The honeybee is a particular pollinator species. Apart from the more general trends and changes mentioned above, the honeybee also suffers the Colony Collapse Disorder (Hendrikx *et al.* 2009; Pizarro and Montenegro 2012; Cepero *et al.* 2014). However, the relationship between honeybees and beekeepers lend to honeybee a complex nature; while the number of hives is increasing worldwide, this does not mean that bee's quality of life is equally improving. Also, the fact that beekeepers tend to generate situations of honeybees' overpopulation, this turns beekeeping into an additional stressor for wild bees and their capacity of provision of pollination, as both wild bee diversity and population might be decreased (Russo 2016; Geslin *et al.* 2017; Alaux *et al.* 2019). Hence, the capacity of honeybees to perform their relevant contributions, in terms of economic return, cultural identity and ecosystem services, is largely depending on a set of undergoing changes and trends, with climate change being one among them.

i. Beekeeping and climate change

In recent years, climate change has been added to the global drivers affecting the viability of beekeeping. The main expected climate trends (Horizon 2030) in the Spanish Mediterranean region are an increase in temperature - 1ºC approximately - and a decrease in precipitation - up to 50% -, which will also become more irregular (REFERENCE). Hence, the displacements of seasons, drought, rising temperatures and increasing extreme events are the main expected effects of climate change in the Mediterranean region (Table 1).

[INSERT TABLE 1 AROUD HERE]

The literature describes different potential impacts of climate change on managed honeybees (Goulson *et al.* 2015): (i) gap between honeybees' phenology and pollinated species and subsequent decoupling, flowering periods are advanced (Fitter and Fitter 2002; Menzel *et al.* 2006); (ii) changes in the distribution area of pollinated species, which entails spatial mismatches between honeybees and pollinated species (Fitter and Fitter 2002; OECC 2008;); (iii) changes in the distribution and virulence of pathogenic species (Le Conte and Navajas, 2008), such as *Nosema cerana* which can develop at a higher temperature range than the less virulent *Nosema apis* (Martín-Hernández *et al.* 2009); (iv) impairment of the degree of survival of non-native invasive species (Walther *et al.* 2009); (v) food shortage at certain times of the year due to the reduction of the flowering length and intensity leading to nutritional problems (Rami Reddy *et al.* 2012; Gómez *et al.* 2013); (vi) the aggravation of other factors threatening honeybees, such as habitat loss and fragmentation (Garibaldi *et al.* 2011; Morandin and Kremen 2013; Hevia *et al.* 2016). Finally, the relation between the increase of atmospheric CO_2 and a reduction in the protein content of pollen should be considered (Ziska *et al.* 2016).

Lastly, it must be kept in mind that although wild bees and managed honeybees largely share the nature of the threats they are being exposed to, some attributes of the domestic honeybee, such as its sociability, long foraging periods, wide and varied diet, and considerable flight distances, endow it with a series of characteristics that make it one of the pollinating insects with the greatest capacity to adapt to changes, as it is the case of changing climatic trends (González-Varo *et al.* 2013). Obviously, to this it should be added the frequently supporting role of beekeepers for the managed honeybees.

ii. Spread of diseases

The spread of diseases, whether due to increased international trade or natural transmission, is a driver associated to the widespread vulnerability of honeybees (González-Varo *et al.* 2013; Forfert *et al.* 2015). Multiple potential pathogens can affect a colony of honeybees, being varroosis, virosis and nosemosis the most reported. In this sense, we need to emphasize the transmission of pathogens from honeybees to wild bees and vice versa (Colla *et al.* 2006; Potts *et al.* 2010). There is a broad consensus in pointing to varroosis as the most important health problem in global beekeeping, with only certain small islands been kept free of varroa (Gómez 2014). The eradication of varroosis is not yet within reach.

iii. Spread of species hostile to the honeybees

Multiples are the species which have the potential capacity of becoming a threat for honeybees' colonies. These include mammals (e.g., *Meles meles* or *Ursus arctos*), insectivorous birds (e.g., *Merops apiaster*), lepidoptera (e.g., *Acherontia atropos* - or *Galleria mellonella*), different types of wasps (e.g., the Asian wasp *Vespa velutina*) or coleopteran (e.g., the *Cetonia melicivorus* beetle). However, more studies are needed to determine the exact magnitude of the effects in each case. Although it is common in the beekeeping sector to consider the bee-eater as a major predator responsible for limiting the foraging of the worker bees, several studies relativize its impact (Alfallah *et al.* 2010; Pérez and Mir, 1988). Among the recent threats, we should note the Asian wasp. It is estimated that honeybees make up at least one third of the Asian wasp's diet (EFSA 2014) and that a single wasp can catch between 25 and 50 honeybees per day.

iv. Habitat loss and fragmentation

Honeybees are very sensitive to landscape changes, and specifically to the loss and fragmentation of habitats (Brown and Paxton 2009; Morandin and Kremen 2013; Hevia *et al.* 2016). Namely, agriculture intensification in some areas, the expansion of monocultures, the abandonment and loss of traditional agricultural practices associated with the maintenance of highly biodiverse habitats and the spread of other land uses are four of the most notable changes in the landscape threatening honeybees and beekeeping. The loss and fragmentation of habitats and their consequent homogenization and loss of biodiversity result in less quantitative and qualitative availability of pollen and nectar for honeybees. Increasing evidence indicates that access to a variety of pollen from a multitude of vegetation is associated with higher health levels in honeybees (Alaux *et al.* 2010).

v. Intoxication

Neonicotinoid insecticides and acaricides are the two types of products most associated with honeybee intoxication. Acaricides are directly administered into the hive. By contrast, neonicotinoids meet the hive through multiple routes, because of their highly persistent nature. Their lethal (Kessler *et al.* 2015; Krupke *et al.* 2012; Goulson *et al.* 2018) and sublethal effects (Desneux *et al.* 2007; Orantes-Bermejo *et al.* 2010; Henry *et al.* 2012; van der Sluijs *et al.* 2013) on honeybees have been described in numerous studies. Other types of intoxication have also been described, such as air pollution (Girling *et al.* 2013) or even exposure to electromagnetic fields (Walcott 1974).

vi. Colony collapse disorder

The colony collapse disorder consists of the inexplicable disappearance, in a short period of time, of a large portion of the population of worker bees in hives which, nevertheless, present normal amounts of breeding and food in reserve. The disorder usually occurs with an absence of dead honeybees inside the hive or in its surroundings. In the final stage, the queen is usually left in the hive with only a few new-born workers. The first reports of the occurrence of Colony Collapse Disorder appeared in 2004 in Europe, and in 2005 in the United States (Pizarro and Montenegro 2012). In 2006/2007 and 2007/2008 a mortality rate of more than 30% was reported in hives in the United States, which set off many alarms. In Europe, in the winter of 2009/2010, mortality rates of 19.2% were described (COLOSS 2017). In Spain, it was first reported in 2000. In the 2004/2005 and 2005/2006 beekeeping seasons the disorder was particularly virulent, with farms reporting losses between 40 and 80% of the combs (Gómez *et al.* 2013). Multiple causal agents have been proposed and there is growing consensus on the multi-causal nature of the decline in honeybees and other pollinating insects in many regions of the world (Hendrikx *et al*. 2009; Cepero *et al.* 2014; Watson and Stallins 2016).

It should be underlined that large-scale losses of hives are not a new experience. Underwood and van Engelsdorp (2007) note that since 1869 there have been at least 18 documented isolated episodes of unusually high mortality rates in honeybee colonies in different parts of the world. In some cases, the losses were similar to those described in the colony collapse disorder. Many of these episodes continue today without a clear explanation of their causes (Van Engelsdorp and Meixner 2010).

Considering al the above, the main objective of this work was to characterize the vulnerability of Mediterranean beekeeping to global environmental change, and particularly to climate change, and identifying the adaptation strategies being conducted by beekeepers. In addition, we will try to prove the hypothesis that different beekeeping production systems suffer differently the impacts of the transformations and thus, adaptation strategies are also diverse. In particular, we compare large, medium and small beekeepers in Mediterranean Spain.

2. Materials And Methods

2.1. Conceptual framework: contextual vulnerability of beekeeping

In line with the growing consensus on picturing vulnerability as comprising multiple impacts and drivers (O'Brien and Leichenko 2000; O'Brien *et al*. 2004; IPCC 2014), different transformations occurring in the climate must be brought into context with other social, political and ecological transformations, occurring in parallel and jointly shaping the landscape where honeybees are kept, and beekeeping is practiced. Accordingly, the concept of vulnerability used in this article stems from the notion of contextual vulnerability that propose an integrated approach to interpret the links between nature and society (Kasperson *et al.* 2005; Adger 2006; Gallopín 2006). Here, we emphasize the dual nature of these complex systems, produced and reproduced by both social and ecological aspects. This notion of vulnerability as a feature of complex socio-ecological systems is an interpretation which is increasingly used to holistically understand the implications of global environmental change in specific domains (Turner *et al.* 2003; Ionescu *et al.* 2009; Fraser *et al.* 2011; Ribot 2011; López-i-Gelats *et al.* 2016). Thus, the notion of vulnerability has been applied within a context of global environmental change in which climate change is one of multiple drivers occurring simultaneously, and where beekeepers and honeybees adapt. In such complex environments, it is very often impossible to establish relationships of direct causality or clear attributions.

2.2. Methodology

In order to characterize the vulnerability of Mediterranean beekeeping to climate change, both interviews and focus groups were employed. A total of 196 structured interviews were conducted with beekeepers from Mediterranean Spain – particularly from Andalusia, Valencia, and Catalonia. To avoid biasing the sample, the number of interviews conducted in each region was established considering the quantity of beekeepers each region shelters. Thus, given that the whole case study regions considered comprises a total of 9,758 operations (MAPA 2021), sheltering Andalusia, Valencia, and Catalonia 54%, 21% and 25% of them respectively; the same percentages were employed to set up the sampling effort. Thus, from a total of 196 interviews, 108 of them were conducted in Andalusia, 40 in Valencia, and 48 in Catalonia. A total of 33 preliminary interviews were run in 2016, while the rest were run in 2020. The interviews were run in person. In addition, a couple of focus groups with beekeeping experts and members of the Spanish Office for Climate Change were held in Valencia and Madrid in June 2015 and October 2016 respectively, to develop and validate the interview. Hence, the interview was designed to collect data on the following domains: general aspects of the beekeeping farm, comprising workforce availability, number of hives, type of production, commercialization channels employed and attitudes towards their activity; the main transformations and trends affecting both beekeepers and honeybees, including the climate, policy, economy, social, ecology and management elements; the adaptations being adopted by beekeepers to benefit or to protect from the transformations undergoing; and finally the main problems, needs and possibilities beekeepers identify in the sector.

Following the conceptual framework of vulnerability, the variables analyzed were grouped into four thematic groups: *general description*, with the main attributes of the honeybee farms; *exposure*, with the characterization of the fundamental changes beekeeping is coexisting with; *adaptation strategies*, with a list of the practices beekeepers implement to deal with or benefit from the transformations; and *sensitivity*, with the main obstacles to and potentialities of beekeeping as well as needs and possibilities. A total of 151 nominal variables emerged from the interviews. Only those variables with a frequency greater than 5% were kept for the analysis, that is 137 nominal variables. Finally, using the SPAD 5.5 program (SPAD 5.5, 1996), we performed a statistical analysis of the data to identify the characterizing elements of the vulnerability of Mediterranean beekeeping according to the size of the honeybee farms. In particular, and in view of the polarized nature of the sector in terms of number of hives managed, three groups of farms were considered, those with fewer than 25 hives, those between 25 and 150 hives, and finally those professional beekeepers with more than 150 hives. The differences between the three groups were examined with the Chi square statistical test).

3. Results

3.1. General description

Almost all the beekeepers interviewed produce honey and 61.7% of them also produce other types of products or services, mostly pollen, propolis, pollination for agriculture, royal jelly, and swarms. The production of pollen and swarms is the main alternative. Self-consumption and direct sale are the main forms of commercialization. Only professional farms dedicate their efforts full-time to beekeeping. All other farms combine beekeeping with other economic activities. At the same time, it is important to underline that professional farms have also larger family tradition. Another relevant aspect is that most beekeepers mention non-economic motivations for carrying out this activity, specifically the existence of a long family tradition of beekeeping, beekeeping as a valuable hobby and beekeeping as a lifestyle that allows to be closer to nature. Generally, it seems that there is a light trend towards increasing the number of hives among the Spanish Mediterranean beekeepers (see Table 1). Also, the interviews revealed that the financial and economic crisis of 2008 in Spain drove some people, generally with certain family tradition of beekeeping and with available land, to consider resuming beekeeping for a living, noting the 'buffer' effect that agriculture in general, and beekeeping in particular, has in the Spanish economy.

[INSERT TABLE 1 AROUND HERE]

3.2. Exposure: Climate and non-climate stressors

There is a broad consensus among the beekeepers interviewed pointing out the displacement of seasons and, especially, the irregularity of precipitation, rising temperatures, and drought as the climate trends that are increasingly affecting honeybees. There is much less consensus concerning the other climate trends mentioned. It is important to emphasize the high degree of consensus, both in terms of identifying climatic changes and their impacts, between specialized literature and beekeepers (Table 2). Figure 1 shows the most important climate stressors for the different farm types analyzed in this article.

[INSERT TABLE 2 AROUND HERE]

Non-climate stressors refer to changes occurring at the policy, economic, social and ecological spheres, as well as changes in the management of farms (Figure 2 and Table 3). In the policy sphere professional farmers mention marginalization - that is, regulations that are not adapted to the reality of beekeepers -, the pollination premium and agri-environmental measures as policy-related issues most affecting their activity. Medium-sized farms, however, identify the existence of subsidy hunters, poorly adapted regulations, outdated sanitary programs and hyper-sanitary regulations. It should be emphasized that many of the administration subsidies designed for the sector can only be requested by farms with more than 150 hives. However, certain grants such as agri-environmental and pollination premiums, and certain regulations, like those for local products, are highly valued. This points to the coexistence of diverse discourses on agricultural policy (López-i-Gelats and Tábara 2010).

[INSERT FIGURE 1 AROUND HERE]

In the economic sphere, the interviewees identified many transformations: coexistence with industrial agriculture, settlement conflicts, competition with low-quality and very cheap imported honey, and theft of honeybees and hives (Figure 2 and Table 3). Virtually, 100% of the interviewees state it is impossible to live in harmony with industrial agriculture and, most notably, with insecticides. Beekeepers frequently mentioned crops such as rapeseed, corn and cotton as having harmful consequences for neighboring hives.

[INSERT TABLE 3 AROUND HERE]

In the social sphere, both the medium-sized and smaller honeybee farms, are the ones most exposed to these types of stressors (Figure 2 and Table 3). Increased awareness of the importance of bees and other pollinators, growing interest in local and ecological products, increased sensitivity of producers to organic beekeeping, and increased demand for healthy products are the primary changes.

[INSERT FIGURE 2 AROUND HERE]

Concerning the ecological drivers, while there is universal consensus in highlighting the spread of diseases, professional beekeepers give more importance to the spread of enemy species, such as the bee-eater (Nombre científico). Beekeepers with fewer than 25 hives underline the effects of the shortening and concentration of the flowering period on their activity; and beekeepers with medium-sized farms stress the effects of habitat loss and fragmentation, the disappearance of wild hives, the pollination crisis (including wild pollinator insects), the hybridization of the black bee with other improved breeds (which is making it lose some of its traditional qualities), and the spread of exotic species (such as the Asian wasp).

Regarding the management field, all three types of honeybee farms agreed in highlighting that some of their colleagues are not rigorous in their sanitary efforts and make inadequate use of sanitary treatments, which may become new sources of the spread of diseases. The smaller farms also point to the incidence of the use of foreign breeds of honeybees as a very important transformation. Finally, it is important to point out the difference between professional and non-professional beekeepers in mentioning the increase of prophylaxis in treatments. While this is a practically insignificant change for professionals, the rest of the beekeepers agreed in considering it a relevant transformation. This would be carried out by managing density at four levels: in the hive, in the apiary, in the settlement, and during mobility.

3.3. Adaptation options

The adaptation strategies that beekeeping farms implement to deal with, or benefit from, the transformations that the sector is currently undergoing often differ depending on the degree of professionalization (Figure 3 and Table 4). Six groups of adaptation strategies have been identified: (i) diversification; (ii) mobility; (iii) intensification; (iv) agroecology; (v) cooperation and finally, (vi) a sixth group with a diverse nature that we have agreed to call 'others'.

[INSERT TABLE 4 AROUND HERE]

Diversification strategies are very common to adapt to highly uncertain situations (López-i-Gelats *et al.* 2011; López-i-Gelats *et al.* 2015) which is used by both the larger and the smaller honeybee farms. Although the pattern is similar in all three categories, farms with fewer than 25 hives use these strategies to a lesser extent. In medium-sized farms, economic and settlement diversification is widespread. Professional farms notably employ the strategy of diversifying products from the hive.

Mobility allows access to more food for honeybees, although transporting hives, especially long-distance displacements, can affect the animals' health (Henry *et al.* 2012). Smaller farms practice more sedentary beekeeping, and as farms handle more hives, they tend to gradually rely more on transhumance.

Implementing intensification strategies, that is, the use of larger quantities of inputs, constitutes another family of adaptation strategies (López-i-Gelats *et al.* 2016). With them, beekeepers try to isolate their production from the uncertainty of changing environmental conditions. In particular, the use of artificial feeding, greater use of inputs and the purchase of new lots are the most common adaptation strategies within this family (see Table 4).

The group of agroecological strategies focuses on ensuring the reproduction of the hives instead of production of honey or other products (IPEs-Food 2016). Small and medium-sized farms adopt these strategies more often than professional farms, especially ecological production strategies, maintaining low hive and apiary densities, adapting the handling to the honeybee's nature (e.g., vertical hives), and using high-quality brand products (see Table S3 in the Supplementary Material). Professional beekeeping farms are only at a similar level of implementation to the other two types of farms in using a native breed of honeybee (the black bee) and in direct sales.

[INSERT FIGURE 3 AROUND HERE]

As with the previous case, the group of strategies focused on mutual support and collaboration among beekeepers is more commonly implemented by small and medium farms. In professional farms, as in the rest, the dependence on family labor and, to a lesser extent, payment in kind (e.g., honey for housing hives) stands out. Farms with fewer than 25 hives are notably involved in cooperatives and participatory health projects. Meanwhile, among the medium-sized farms we can highlight the participation in cooperatives, payment in kind and relatively high levels of implementing labor exchanges with colleagues and collaborations with partners on health issues (e.g., collective purchase of treatments).

3.4. Sensitivity: Perception of the problems, needs and possibilities of the beekeeping sector

As described in the previous section, the beekeeping sector in the Mediterranean region carries out the activity in an environment where multiple transformations interact with often unknown or uncertain implications. These transformations do not have the same consequences in all beekeeping farms. Below we examine the main problems, needs and possibilities identified by beekeepers (Figure 4 and Table 5) in relation to all the climatic and non-climatic transformations mentioned before.

[INSERT TABLE 5 AROUND HERE]

The three types of farms identified different problems in the beekeeping sector (see Table 5). Nevertheless, all agreed on attributing a fundamental role to the problem of coexistence with industrial agriculture, especially with the use of neonicotinoid insecticides, and to the existence of diseases, many of which have appeared recently. The development of inadequate policies - that is, policies that are not in line with the nature of beekeeping - is particularly alarming for medium-sized and large farms. Small farms, being sedentary and not reliant on subsidies, prioritized other problems. A quarter of beekeepers, mainly from large farms, pointed to climate change as a relevant problem, especially due to its consequences in the deterioration of the quality and quantity of the honeybees' diet and the greater difficulty in finding suitable settlements. Similarly, settlement conflict is referred to as a problem only by larger farms, especially those using transhumance. Regarding the needs expressed by the sector there is a broad consensus. Reducing the levels of bureaucracy and providing more training for beekeepers are the needs most mentioned by the medium-sized and small farms. Professional beekeepers mostly refer to the need for greater awareness of the role that honeybees and pollination in general play, as well as the benefits for health and biodiversity of many of the products and services derived from the beehive. Beekeepers also highlighted the need to develop effective health treatments.

Despite the remarkable magnitude and diversity of the challenges beekeeping face, beekeepers identified a number of possibilities. Mainly seen by medium-sized beekeepers, the major potentiality is the valuation of ecosystem services guaranteed by bees, either to improve the image for consumers and policy makers or as an economic strategy involving payment for environmental services. Small beekeepers point out the potential of agroecological management and their ability both to provide a product that is increasingly required by a larger segment of the population and to offer management options based on prophylaxis - instead of the currently predominant therapeutic route - against current multiple threats.

4. Discussion

There is large consensus in pointing the importance of beekeeping for multiple reasons: economic (European Commission, 2015), cultural (Roffet-Salque *et al.* 2015) and as a major provider of fundamental ecosystem services due to the nature of honeybees as pollinators (Balvanera *et al.* 2005; Kremen 2005). However, there is also wide consensus among specialists in pointing that the capacity of honeybees and beekeepers of undertaking the relevant contributions, in terms of economic return, cultural identity and ecosystem services, depends on their capacity of facing a set of challenges posed by several undergoing transformations. Some of these challenges are shared with wild bees (Steffan-Dewenter *et al.* 2005; Biesmeijer *et al.* 2006) but in the sector, we have found that size of the farm is a particular factor that affects how those transformations are perceived by beekeepers but also the adaptation strategies they put in practice.

The specialized literature points to six main groups of transformations undermining honeybees and beekeeping: (i) Spread of diseases (Cameron *et al.* 2011, Forfert *et al.* 2015); (ii) Spread of species hostile to honeybees (Moron *et al.* 2009); (iii) Habitat loss and fragmentation (Garibaldi *et al.* 2011); (iv) Intoxication by both pesticides form industrial agriculture and acaricides form sanitary treatments (Gill *et al.* 2012; Whitehorn *et al.* 2012; Goulson *et al.* 2018); (v) Colony collapse disorder (Hendrikx *et al.* 2009; Pizarro and Montenegro 2012; Cepero *et al.* 2014)M; and climate change (Memmott *et al.* 2007; Hegland *et al.* 2009). The complex nature of the vulnerability of honeybees and beekeeping, comprised by both climate and non-climate transformations, is also underlined by the beekeepers of the Mediterranean Spain. The main groups identified by the specialized literature were also identified as very relevant. A total of 51 different transformations were reported by at least 5% of the beekeepers interviewed (Table 3).

However, the diversity of transformation affecting honeybees and beekeeping that beekeepers reported points the existence of a relevant void in the specialist literature, which is that of the transformations occurring within the socio-economic and policy domains (Figure 2). The damaging consequences of inappropriate policies or policies not accurately designed to deal with the necessities of beekeeping was widely reported by beekeepers. Also, the need to be aware of several trends in society was seen as very relevant by beekeepers, such as increasing demand for local, organic, and healthier products, as well as the increasing social awareness of the key role of honeybees as key pollinator agents. A good number of economic transformations was also reported by beekeepers as mediating their activity very much. While the challenge of coexistence between industrial agriculture and beekeeping is largely present in the literature (e.g., Whitehorn *et al.* 2012; Goulson *et al.* 2018), other economic transformations were also reported by beekeepers that tend to be dismissed by specialized literature. This is the case of rise in fuel price, and the coexistence with uninformative labels and poor-quality honey in the marketplace.

[INSERT FIGURE 5 AROUND HERE]

Concerning the implications of climate change for beekeeping, it is interesting to underline the large degree of consensus between the specialized literature and the beekeepers interviewed from Mediterranean Spain. Changing precipitation patterns, drought and temperature rise are the climate trends more stressed by beekeepers (Figure 1) as well as more expected by scientific projections (AEMET, 2016). The consensus is also wide with the implications of climate transformation for beekeeping. Thus, both beekeepers (Table 2) and the specialized literature (e.g., Menzel *et al.* 2006; Le Conte and Navajas, 2008; Martín-Hernández *et al.* 2009; Walther *et al.* 2009; Gómez *et al.* 2013; Goulson *et al.* 2015; Hevia *et al.* 2016; Bezner-Kerr et al., (2022)) underline the following implications: (i) enlarging gap between honeybees' phenology and pollinated species; (ii) changes in the distribution and virulence of pathogenic species, (iii) spread of species hostile to honeybees; and (iv) food shortage at certain times of the year due to the reduction of the flowering length and intensity. It should be noted that climate change was not mentioned by the beekeepers as the most pressing transformation they are dealing with (Figure 4). In general, professional beekeepers tend to be more aware of the effects of climate transformations than non-professional beekeepers, probably because their food requirements are larger.

The vulnerability of honeybees and beekeeping is not only characterized by the existence of a good number of transformations, but also by the capacity beekeepers show in dealing with these transformations, which is also very diverse and significant. A total of 43 different adaptations strategies were reported by at least 5% of the interviewed beekeepers in Mediterranean Spain to be employed to face the ongoing transformations (Table 4). Diversification, Mobility, Intensification, Agroecology and Cooperation were the main groups of adaptation strategies being reported. While Diversification, Cooperation, Mobility and Intensification are types of adaptation strategies being reported in the sector for long time, and comprise practices widely spread among Mediterranean beekeeping; the diversity of the Agroecological types of adaptation strategies, comprised by traditional and new practices should be particularly highlighted (Figure 3).

The large number of transformations honeybees and beekeepers are exposed to and the large capacity of beekeepers to deal with them in different manners are differently mediated by the size of the beekeeping operations. While the perception about both climate and non-climate transformations is rather similar among beekeepers running operations of different size (Figure 1); the different resources available and objectives of professional and non-professional beekeepers seem to be behind the implementation of different adaptation strategies. As suggested by Rivera-Ferre et al. for livestock farming (2016), we also found that different types of honeybee operations rely on different adaptation strategies. While small and medium non-professional beekeepers tend to devote more on agroecological adaptation strategies (e.g., direct sale, bee-friendly management, autochthonous breeds, organic production or reducing beehive extraction to better guarantee the health of the hive) putting emphasis on guaranteeing the quality of the products they produce; professional beekeepers tend devote more on management diversification and mobility to guarantee the food security of their large number of hives (Figure 3). This is largely in line with the problems, needs and possibilities the different beekeepers identify. Unlike professional beekeepers, non-professional beekeepers focus more on enhancing the quality of the beehive products to satisfy the increasing demand of high-quality products, by means of identifying the need of more training for them, greater facilities for local sale, and more precise quality and origin labelling (Figure 4).

Finally, despite the remarkable magnitude and diversity of the challenges honeybees and beekeeping are facing, the beekeepers interviewed also identified a number of emerging possibilities for the sector (Figure 5): (i) the valuation of ecosystem services guaranteed by honeybees and beekeeping, either to improve the image of beekeeping for consumers and policy makers or as an economic strategy involving payment for environmental services; (ii) non-professional beekeepers point out the potential of agroecological management and their ability both to provide a high-quality product and healthier product, what is increasingly demanded by a larger segment of the population, and to offer management options based on prophylaxis - instead of the currently predominant therapeutic route - against the current sanitary crises; and finally (iii) the recognition of beekeeping as a high-reliability economic activity as shown by the buffer effect this activity run in economic crises. To finish a major challenge remains on the side of beekeeping to minimize the potentially damaging effects the great concentrations of honeybees cause to their wild counterparts and on the capacity of wild bees of guaranteeing the pollination and other services they also secure (Geslin *et al.* 2017; Alaux *et al.* 2019).

5. Conclusions

The study discloses the complex nature of the vulnerability of Mediterranean beekeeping, with climate change being a contributing driver. The capacity of honeybees and beekeepers of undertaking multiple relevant contributions, in terms of economic return, cultural identity and ecosystem services, depends on their capacity of facing a set of challenges posed by these climate and non-climate transformations. While the specialized literature tends to focus on biophysical and biological changes and trends (the spread of diseases, the spread of species hostile to honeybees, habitat loss and fragmentation, intoxication by both pesticides and acaricides, the colony collapse disorder, climate change), the results of this work point to the existence of a significant void. The transformations occurring within the socio-economic and policy domains tend to be largely dismissed by the specialized literature. These included the impact of inappropriate policies, the recognition of the existence of several societal trends with major consequences on the sector - such as increasing demand for local, organic and healthier products, as well as the increasing social awareness of the key role of honeybees in pollination; and certain economic transformations - such as, uninformative labels and coexistence with poor-quality honey in the marketplace.

The vulnerability of honeybees and beekeeping is not only characterized by the existence of multiple transformations, but also by the huge and diverse adaptation capacity of beekeepers which is mediated by their size. This is highly relevant in terms of policymaking, since policy makers need to consider this diversity of farming practices when developing appropriate climate policies.

Finally, despite the remarkable magnitude and diversity of the challenges honeybees and beekeeping are facing, the beekeepers interviewed also identified a number of emerging possibilities for the sector although a major challenge remains on the side of beekeeping to minimize the damaging effects to wild bees – and on the capacity of wild bees of guaranteeing the pollination and other relevant services they also secure - when great concentrations of honeybees are kept by beekeepers.

Declarations

Acknowledgments: This research was carried out with the support of the Spanish Ministry of Agriculture, Food and Environment, through Fundación Biodiversidad and Oficina Española de Cambio Climático; as well as Agrupación de Defensa Sanitaria Apícola (APIADS), Coordinadora de Organizaciones de Agricultores y Ganaderos (COAG) and Col·lectiu Abellaires. Special thanks are also due to Fernando Molero, Esteve Miràngels, Enric Simó and Raquel Díaz-Ruiz.

Additional requests Submission: Paula Llaurador: data analysis; Erik Hobbelink: field work; Marta Rivera-Ferre: idea, revision; Feliu López-i-Gelats: idea, field work, writing, data analysis, revision

Ethics approval and consent to participate: The authors declare no competing interests.

Consent for publication: All participants gave consent for this research to be published.

Funding: Paula Llaurador is funded by Universitat de Vic-Universitat Central de Catalunya; Erik Hobbelink is funded by Universitat de Vic-Universitat Central de Catalunya; Marta Rivera-Ferre is funded by Fundación Biodiversidad and Universitat de Vic-Universitat Central de Catalunya; Feliu López-i-Gelats is funded by Fundación Biodiversidad and Universitat de Vic-Universitat Central de Catalunya.

Availability of data and materials: Data will be made available upon reasonable request.

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Tables

Table 1. Main features of honeybee farms in the Spanish Mediterranean considering amount of hives.

	< 25 (24.5%)	**25 ≤ and ≤ 150** (17.3%)	**> 150** (58.2%)
WORKFORCE			
Family tradition	14.6***	38.2	75.4***
Full-time commitment	0.0***	14.7**	50.9***
> 1 worker	29.2	35.3	41.2
> 2 workers	8.3	8.8	16.7
With salaried workers	8.3	2.9	21.9***
TRENDS IN Nº OF HIVES			
Increasing number of hives	22.9	23.5	14.0
Steady number of hives	37.5	41.2	54.4
PRODUCTION			
Honey	97.9	97.1	96.5
Pollen	14.6	11.8	25.4
Propolis	33.3***	8.8	14.0
Pollination	4.2	0.0	14.0**
Royal jelly	2.1	0.0	7.9
Wax	20.8**	35.3	44.7**
Beekeeping services	2.1	5.9	0.0
Swarms	0.0	0.0	13.2***
COMMERCIALIZATION			
Direct selling	37.5***	85.3**	68.4
Through intermediary	12.5***	11.8***	54.4***
Self-consumption	97.9***	79.4**	39.5***
Through cooperative	0.0	0.0	8.8**
VOCATION			
In touch with nature	14.6	14.7	12.3
Family tradition	8.3**	29.4	32.5**
Hobby	79.2**	73.5	52.6***

Working option	12.5	11.8	21.1
Generational succession	87.5***	57.6	57.1**

* $p<0.05$, Chi-square test. ** $p<0.01$, Chi-square test. *** $p<0.001$, Chi-square test.

Table 2. Main expected and observed climate trends and their impacts on beekeeping.

	AEMET PROJECTIONS****				BEEKEEPERS	LITERATURE	BEEKEEPERS
	AND*	**VAL**	**CAT**	**TRENDS**	**TRENDS**	**IMPACTS**	**IMPACTS**
Max annual T**	+	+	+	- Increase of maximum temperatures, mostly in autumn and summer.	- Increase of temperatures (AND: 45.5%; VAL: 72.7%; CAT: 90.9%)***. - Decrease of temperatures (AND: 0.0%; VAL: 18.2%; CAT: 18.2%).	- Divergence between phenology of honeybees and pollinated species. - Spatial mismatches between honeybees and pollinated species. - Occurrence of exotic species. - Changes in the distribution and virulence of pathogenic species. - Aggravation of other non-climate drivers.	- Higher temperatures reduce the flowering length. - Flowering is advanced. - Decoupling between bee and flowering. First flights come earlier in warm years. - Higher temperatures reduce the break in winter (specially in Andalusia). This entails larger production but complicates those sanitary treatments that need to be implemented when the colony is less active. - Spread of species hostile to the bees. - Spread of diseases and changes in their virulence. - Aggravation of other non-climate drivers.
Max spring T	+	+	+				
Max summer T	++	++	++				
Max autumn T	++	++	++				
Max winter T	+	+	+				
Min annual T	+	+	+	- Increase of minimum temperatures, mostly in autumn and summer in Catalonia.			
Min spring T	+	+	+				
Min summer T	++	++	+++				
Min autumn T	++	++	+++				
Min winter T	+	+	+				
Annual P	-	-	=	- Unclear rainfall trends. - Faint rainfall increase for	- Changes in the seasonality of precipitations (AND: 81.8%; VAL: 81.8%;	- Reduction of the flowering length and intensity, leading to food	- Reduction of the flowering length and intensity, which entails food shortage at certain
Spring P	-	=	+				
Summer P	=	=	+				

Autumn P	–	-	-	spring and summer in Catalonia, while minor drop for autumn and winter mostly in Andalusia.	CAT: 100.0%). - Decrease in humidity (AND: 18.2%; VAL: 0.0%; CAT: 0.0%). - Water level decrease (AND: 9.1%; VAL: 27.3%; CAT: 9.1%).	shortage for pollinators. - Aggravation of other non-climate drivers.	circumstances, and complicates the identification of appropriate settlements. - Aggravation of other non-climate drivers.
Winter P	-	-	-				
Warm days length	+	+	+	- Increase in heat waves.	- Increase in droughts (AND: 72.7%; VAL: 72.7%; CAT: 54.5%). - Increase in extreme events (AND: 36.4%; VAL: 0.0%; CAT: 0.0%). - Increase in wind intensity (AND: 9.1%; VAL: 0.0%; CAT: 9.1%).	- Increase in local mortality. - Aggravation of other non-climate drivers.	- Local mortality. - The colony gets weaker and shows larger vulnerability to other drivers. - Less access to pollen and water.
Nº warm days	++	++	++				
Nº frost days	-	-	—	- Decrease in frost, mostly in Catalonia. - Increase in number of warm nights.			
Nº warm nights	+++	+++	+++				
Length of dry spells	+	=	=	- Increase of dry spells in Andalusia. - Unclear trends in number of rainy days. - Decrease in heavy rains.			
Nº rainy days	-	=	+				
Heavy rains	-	-	-				

Note: = means no change; + means increasing intensity; and – means decreasing intensity. *AND means Andalusia; VAL means Valencia; and CAT means Catalonia. ** Max annual T is Maximum annual temperature; Min annual T is Minimum annual temperature; P means precipitations. *** Percentage of people interviewed identifying the given climate trend as relevant for the beekeeping activity per each region in brackets. ****AEMET: Meteorology Spanish Agency (2016).

Table 3. Exposure: the main transformations with which honeybees and beekeeping coexist in the Spanish Mediterranean according to beekeepers from different-sized honeybee farms.

	< 25 (24.5%)	**25 ≤ and ≤ 150** (17.3%)	**> 150** (58.2%)
-			
CLIMATE			
Changes in seasonality of precipitations	85.4	76.5	81.5
Rise in temperature	62.5	67.6	74.5**
Drought	70.8	82.3	85.0
Water level decrease	37.5	44.1	54.3
Extreme events	31.2	41.1	51.7
Reduction in temperature	10.6	8.8	24.5
Humidity decrease	10.4**	20.5	39.4***
Increase in wind intensity	16.6	23.5	23.6
Greater humidity	0.0	0.0	5.0
POLICY			
Inappropriate legislation	62.5	80.0	70.0
Marginalization	50.0	50.0	46.4
Outdated sanitary programs	54.1	47.0	49.1
Agro-environmental schemes	10.4***	26.4	58.7***
Organic production	25.0	38.2	32.4
Subsidy hunting	10.4**	23.5	28.9
Hyper-sanitary regulations	6.3**	23.5	28.9
Pollination premium	6.2***	14.7	35.9
Local product labels	20.8**	38.2	42.1
Bee-eater coexistence regulation	8.5	20.5	21.9
ECONOMY			
Pesticides	93.0***	82.4	93.0***
Monocultures	50.0	50.0	52.6
Uninformative labels	58.3**	64.7	80.7***
Poor quality honey commercialization	62.5***	100.0	80.0***

Settlement conflicts	29.2**	41.2	50.9
Overexploitation	31.3	44.1	45.6
GMOs	35.4	35.3	54.4**
Honey adulteration	54.2***	82.4	86.8***
Theft	31.3**	38.2	58.8***
Shift to crops less adequate for bees	31.3	44.1	46.5
Fuel price rise	16.7***	50.0	64.0***
SOCIAL			
Rising demand for local products	72.6	64.7	58.8
Sensitivity of beekeepers in organic production	43.8	35.3	45.6
People’s awareness of honeybees	62.5	73.5	72.8
Rising demand for healthy products	58.3	61.8	64.9
Rising demand for organic products	54.2	52.9	45.6
Increase in training	60.4**	47.1	33.3**
Generational succession with limited experience	18.8	11.8	23.7
ECOLOGY			
Spread of diseases	79.2	79.4	81.6
Concentration of the flowering period	39.6	44.1	46.5
Spread of species hostile to the honeybees	79.2	70.6	71.9
Colony collapse	66.7	70.6	78.1
Reduction of flowering length	62.5**	76.5	81.6
Disappearance of wild hives	62.5	79.4	59.6
Loss of habitats	58.3	64.7	58.3
Hybridization	20.8	14.7	28.9
Pollination crisis	18.8**	26.5	40.4**
Spread of exotic species	58.3**	50.0	30.7***
Wildfires	18.8	23.5	36.0
MANAGEMENT			
Inappropriate application of sanitary treatments	62.5	67.6	71.9

Inappropriate honeybee welfare management	56.3	55.9	46.5
Employment of foreign breeds of honeybees	31.3	17.6	16.7
Increase of prophylaxis in treatments	29.2	47.1	43.0

* $p<0.05$, Chi-square test. ** $p<0.01$, Chi-square test. *** $p<0.001$, Chi-square test.

Table 4. Adaptation strategies implemented by the beekeeping sector in the Spanish Mediterranean according to beekeepers from different-sized honeybee farms.

	< 25 (24.5%)	**25 ≤ and ≤ 150** (17.3%)	**> 150** (58.2%)
-			
DIVERSIFICATION			
Economic diversification	47.9	55.9	57.9
Beehive product diversification	37.5	23.5	44.7
Settlement diversification	29.2***	52.9	66.7***
Specializationin unconventional beehive products	18.8	17.6	21.9
Honeybee management diversification	43.8	35.3	51.8
Diversification in manufactured products	25.0	17.6	24.6
MOBILITY			
Transhumance	6.3***	38.2	73.7***
Change in settlements	31.3	38.2	52.6**
Sedentary beekeeping	66.7***	50.0	23.7***
Change in transhumance routes	4.2***	20.6	40.4***
Mobility increase	12.5**	32.4	37.7**
INTENSIFICATION			
Artificial feeding	62.5	79.4	65.8
Greater use of inputs	22.9	29.4	28.9
Purchase of new lots of honeybees	20.8	23.5	12.3
Wholesaling	0.0**	8.8	21.1***
Purchase of foreign breeds of honeybees	4.2	5.9	6.1
AGROECOLOGY			
Autochthonous breed	75.0***	44.1	46.5
Direct sale	56.3	76.5	57.0
Managing according to bee’s nature	75.0**	80.0	45.0
Hive location	47.9	47.1	41.2
Low hive densities	45.8	47.1	54.4
Consumer sensitization	41.7	32.3	33.3

Animal welfare	39.6	29.4	37.7
Organic production	56.3**	35.3	33.3
Avoiding certain settlements	31.3	29.4	35.1
Low apiary densities	35.4	35.3	45.6
High-quality brands	27.1	29.4	31.6
Reducing beehive extraction	70.8	61.8	54.4
Local brand products	31.3	35.3	29.8
COOPERATION			
Family labor	75.0	70.6	80.7
Collaboration	41.7	29.4	29.8
Bartering	22.9	44.1	32.5
Participatory management of honeybee welfare	31.3	38.2	31.6
Labor exchange	18.8	29.4	25.4
OTHERS			
Beekeepers' training	75.0	73.5	53.5**
Changing genetic line	14.6**	29.4	35.1
Rotating sanitary treatments	75.0	58.0	62.3
Anti-theft insurance	22.9***	41.2	58.8***
Hive sanitation base	60.4***	26.5	21.9***
Reposition vs productivity	52.1	41.2	45.6
Research	29.2	35.3	42.1
Hives as signs	6.3	11.8	21.9**
Hives to be saved	8.3	5.9	18.4

* $p<0.05$, Chi-square test. ** $p<0.01$, Chi-square test. *** $p<0.001$, Chi-square test.

Table 5. Sensitivity: problems, needs and possibilities for beekeepers in the Spanish Mediterranean.

	< 25 (24.5%)	**25 ≤ and ≤ 150** (17.3%)	**> 150** (58.2%)
-			
PROBLEMS			
Diseases	25.0	26.5	29.8
Inappropriate policies	8.3	8.8	14.9
Pesticides and industrial agriculture	12.5	5.9	11.4
Climate change	6.3	0.0	9.6
Misinformation of consumers	4.2	5.9	2.6
Inappropriate honeybee management	4.2	5.9	4.2
Exotic and invasive species	12.5**	5.9	1.8**
Origin labelling	12.5	23.5	16.7
Economic viability	6.3	8.8	9.6
NEEDS			
Valorization of honeybees	12.5	8.8	10.5
Appropriate sanitary treatments	6.3	14.7	16.7
Consumer sensitization	4.2	8.8	7.9
Reduction in bureaucracy	4.2	8.8	1.8
Beekeepers' training	14.6	14.7	4.4**
Direct sale	14.6	0.0	7.0
POSSIBILITIES			
Valorization of pollination services	18.8	20.6	17.5
Highquality product with increasing demand	20.8	23.5	12.3
Organic, animal-welfare sound management	12.5**	0.0	4.4

* $p<0.05$, Chi-square test. ** $p<0.01$, Chi-square test. *** $p<0.001$, Chi-square test.

Figures

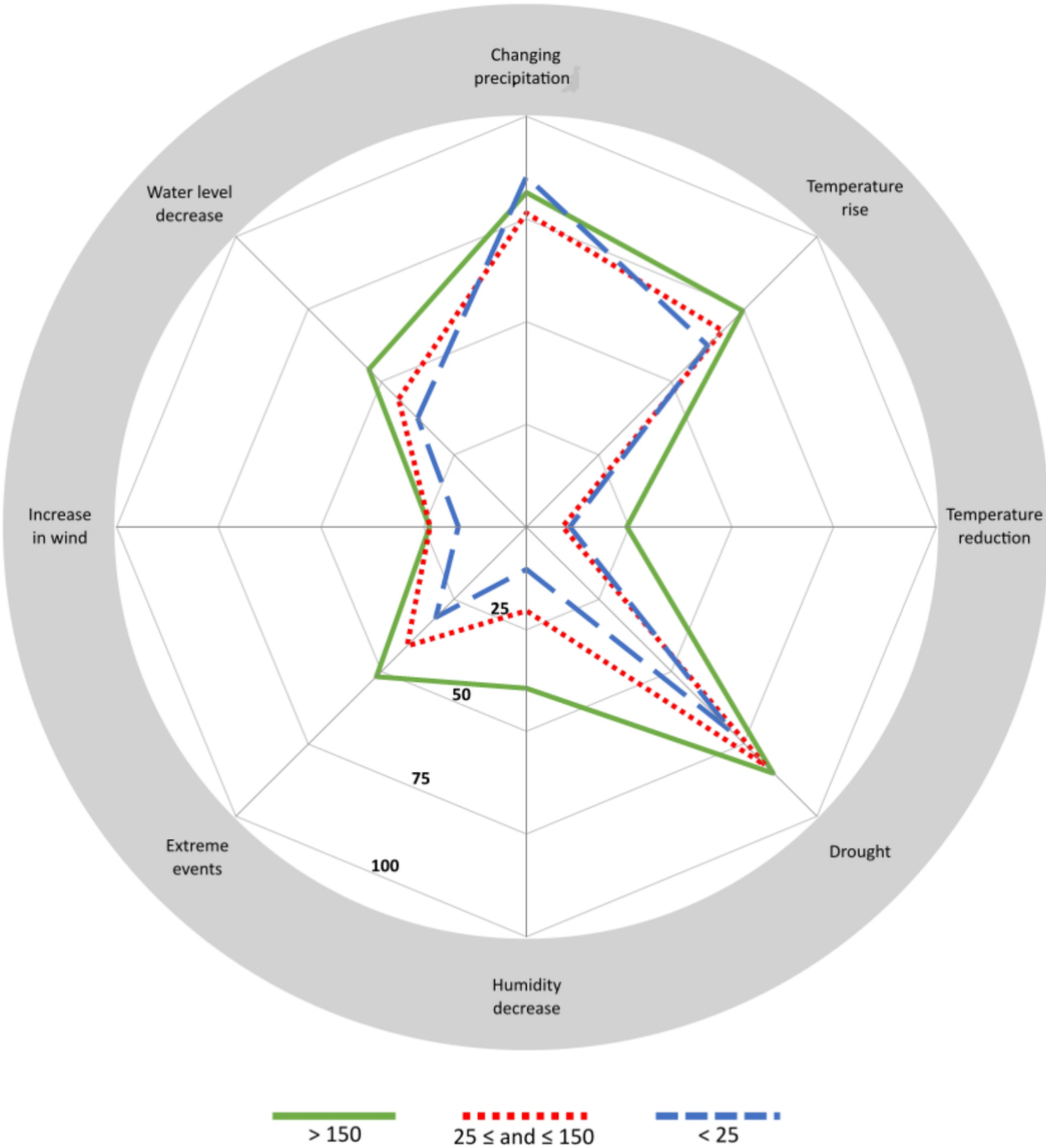

Figure 1

Climate trends identified by Spanish Mediterranean beekeepers managing different number of hives.

Note: See Table 3 for a comprehensive table.

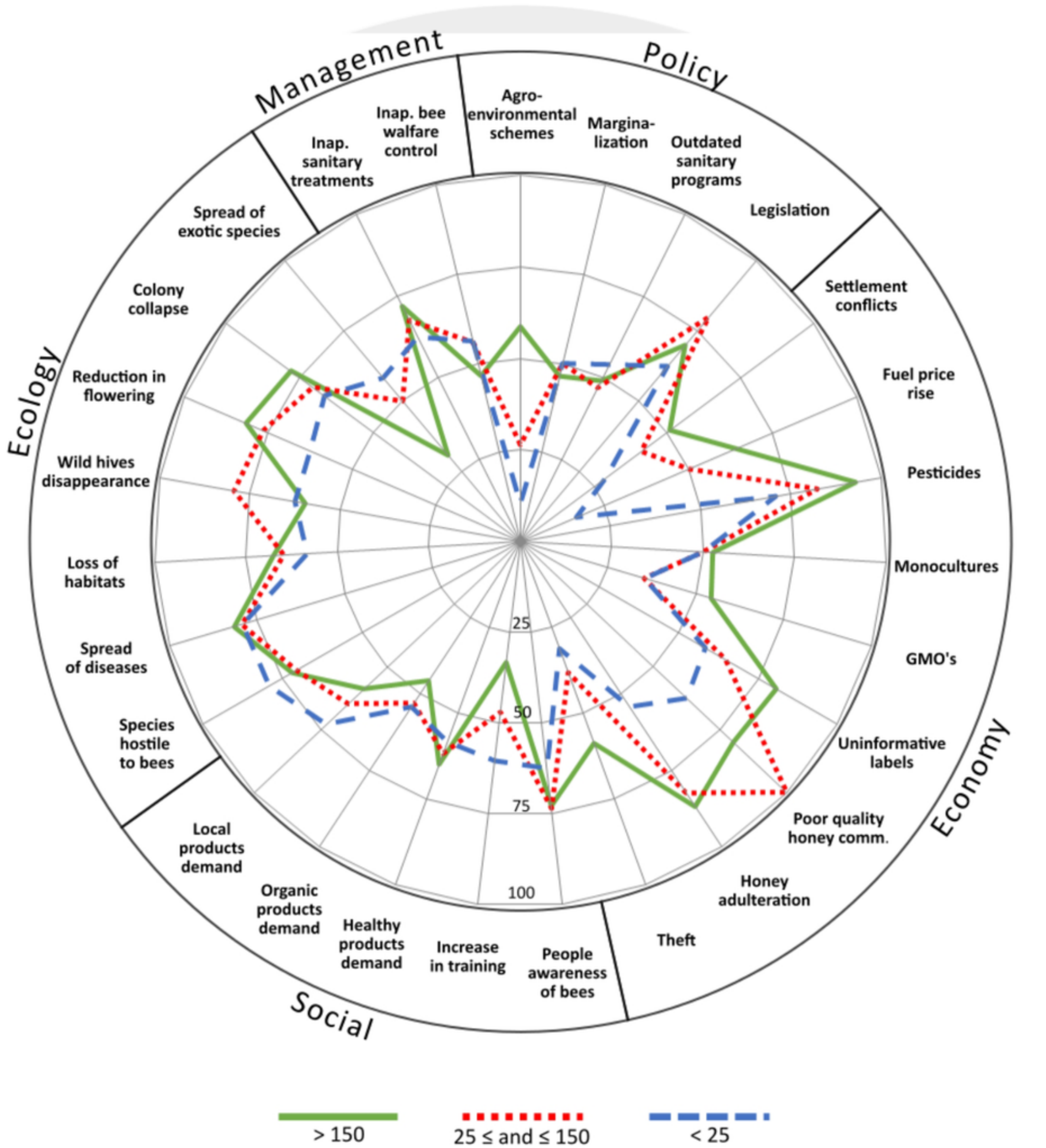

Figure 2

Main non-climate transformations identified by Spanish Mediterranean beekeepers managing different number of hives.

Note: Only those transformations being mentioned at least by 75% of the beekeepers of at least one of the honeybee farm types considered appear in this figure (see Table 3 for a comprehensive table).

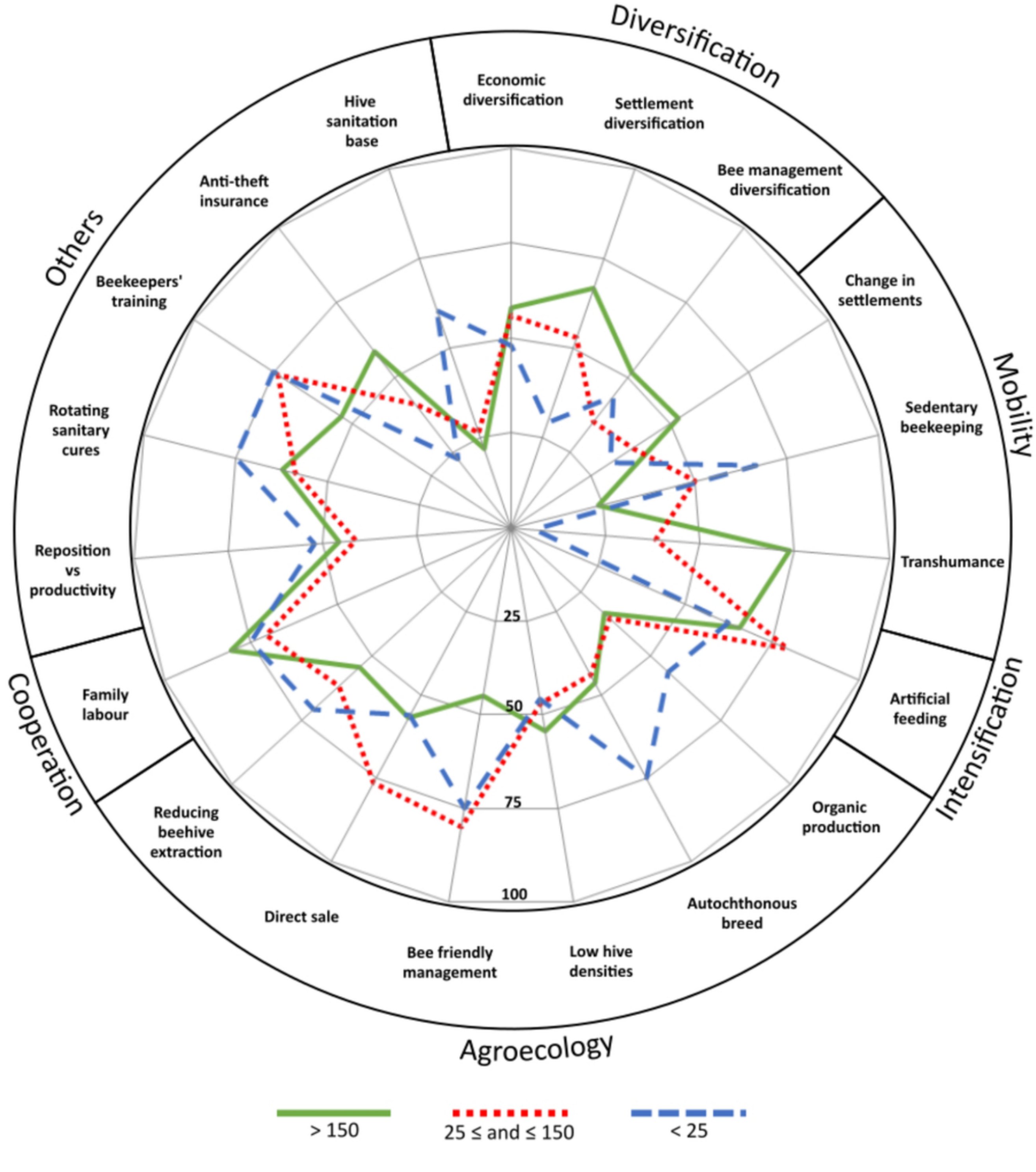

Figure 3

Main adaptation strategies being adopted by Spanish Mediterranean beekeepers managing different number of hives.

Note: Only those adaptation strategies being mentioned at least by 75% of the beekeepers of at least one of the honeybee farm types considered appear in this figure (see Table 4 for a comprehensive table).

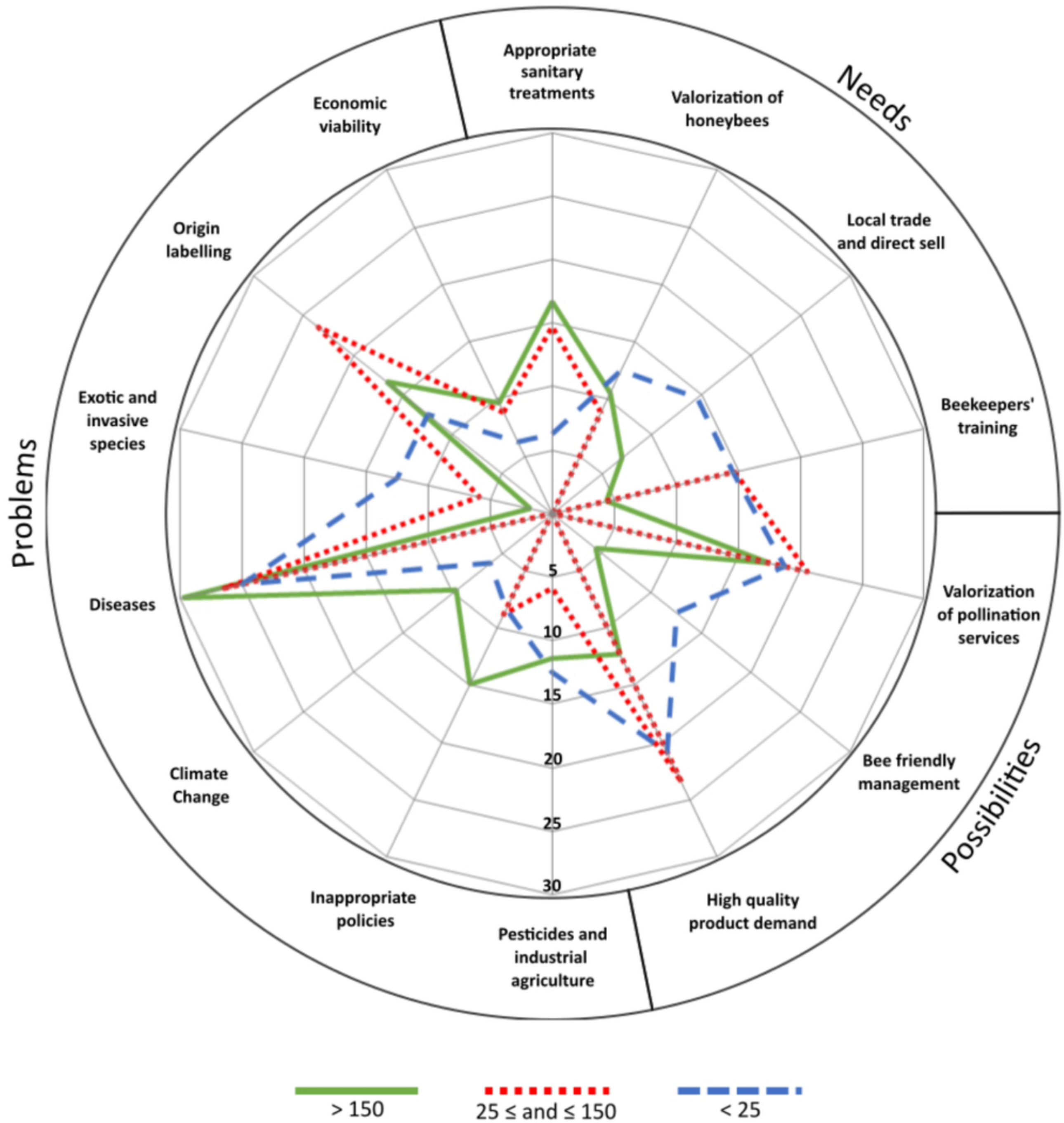

Figure 4

Problems, needs and possibilities being identified by Spanish Mediterranean beekeepers managing different number of hives.

Note: See Table 5 for a comprehensive table.

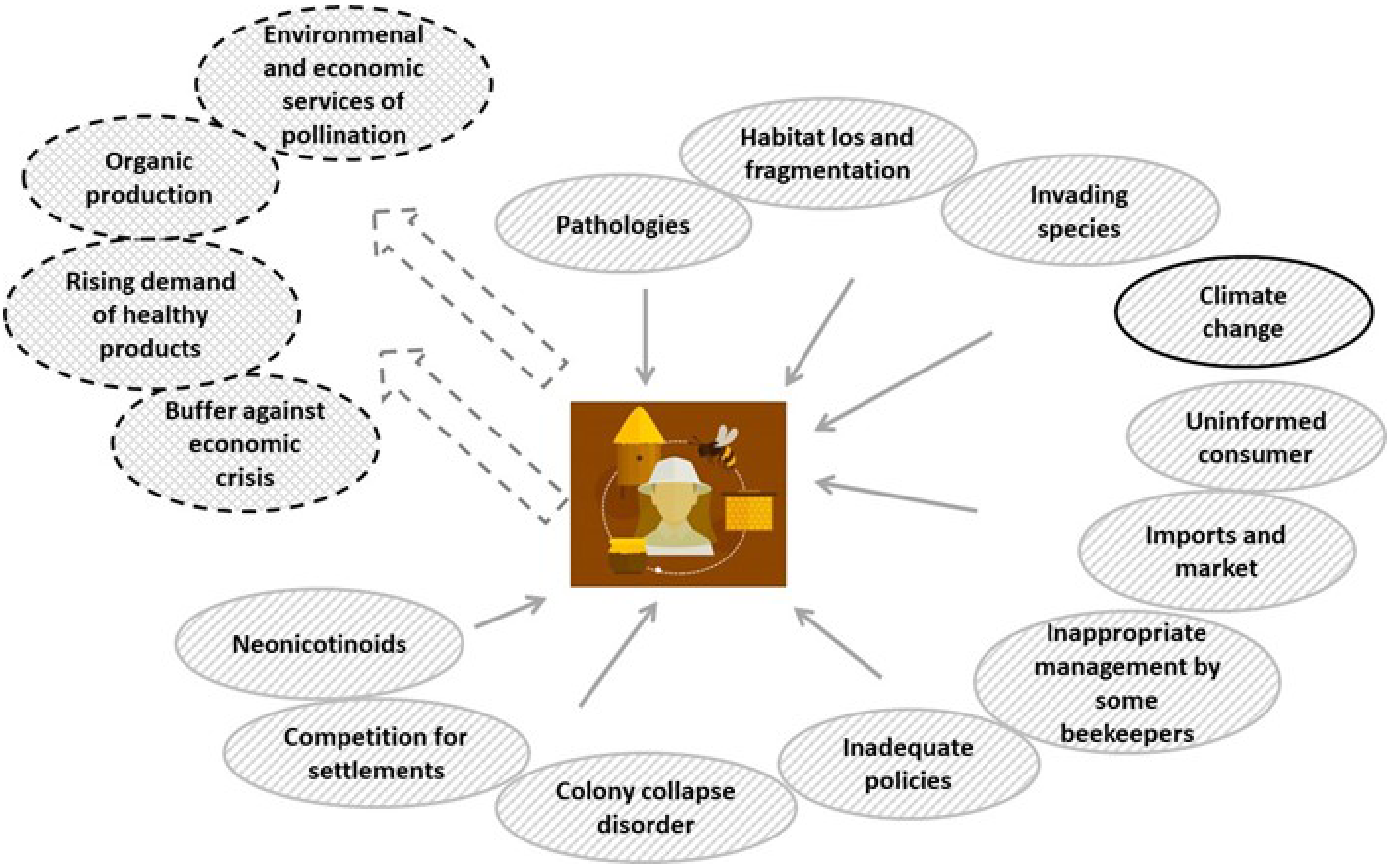

Figure 5

The complex vulnerability of Mediterranean beekeeping.