Regional Environmental Change (2024) 24:79
https://doi.org/10.1007/s10113-024-02242-3

ORIGINAL ARTICLE

‘The rules of nature are changing; every year is unpredictable’: perceptions of climate change by beekeepers of Liguria, NW Italy

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Received: 5 November 2023 / Accepted: 25 April 2024 / Published online: 15 May 2024

Abstract

Beekeeping activity is a privileged lens for looking at the impacts of climate change since this human activity is profoundly and intimately embedded in the local ecology with particular reference to the flora. Therefore, we conducted 47 semi-structured interviews to identify the local perceptions of climate change impacts and their drivers among beekeepers of Liguria, a mountainous region of NW Italy. We found that beekeepers especially noticed changes in bee productivity and behaviour and melliferous flora productivity. Moreover, drought is a significant driver of changes in beekeeping as it affects both bees and melliferous plants. However, other drivers, namely alien species, pesticide spread, and abandonment of small-scale agriculture, also concur synergistically. We conclude that landscape planning sensitive to the needs and requests of beekeepers can further contribute to their adaptation to the impacts of climate change and reduce other detrimental phenomena on honeybee wellbeing by supporting small-scale agriculture to maintain a diverse landscape that provides fodder for pollinators.

Keywords Apiculture · Environmental change · Ethnobiology · Global changes · Honey

Introduction

The abrupt climate change we are experiencing requires a multidimensional understanding of the phenomenon. While instrumental measurements provide crucial information about climate variations, often on long-term temporal scales in a specific location, local populations could report the impacts of climate change they perceive (and experience).

Communicated by Yolanda Pueyo

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In this sense, several researchers have recently addressed the issue of the locals’ perception of climate change in diverse settings (Byg and Salick 2009; Reyes-García et al. 2024a, 2024b). Studies of this kind are crucial for understanding how local ecological knowledge and practices (LEK) are adapting and, therefore, for sustaining local communities in their resilience strategies. In Europe, these studies are very recent and mainly address mountain regions such as the Romanian Carpathians (Babai 2024; Mattalia et al. 2024), the Sierra Nevada (Spain) (García-del-Amo et al. 2024), and the Alps (Fuchs et al. 2024).

Among different livelihoods, beekeepers are a privileged lens for looking at climate change perceptions since this human activity is profoundly and intimately embedded in the local ecology, flora, and landscape. The Western honeybees (*Apis mellifera* Linnaeus, 1758) are considered the ‘pollinators par excellence’, and it is widely accepted that their disappearance, or even their rarefaction, would make life on the planet problematic due to the reduced agricultural productivity and the loss of biodiversity of natural habitats (Potts et al. 2010; Rortais et al. 2017). This is because domesticated honeybees are super-generalist insects able to pollinate a wide range of plant species (Valido et al. 2019). In Europe, this can contribute to the decline in wild pollinators due to the competition for floral resources and their potential role as pathogen vectors (Hung et al. 2018; Herrera 2020; Papa et al. 2022). However, considering the major land use changes occurring in Europe and the consequent disruption of the ecological interactions between specialist pollinators and their habitat and floral resources, domesticated honeybees play a crucial role in pollination (Valiente-Banuet et al. 2015; Verhagen et al. 2018). In Italy, the role of domesticated honeybees is pivotal not only from their contributions in terms of pollination (e.g. in Central Italy sunflower yields strongly depend on nomadic beekeeping; Bartual et al. 2018), but also for the historical-cultural significance of beekeeping (Fontana et al. 2018).

Nevertheless, we are experiencing a decrease in pollinators, specifically bees, due to three leading causes of pollinator decline: climate change, land cover change, and pesticides (Janousek et al. 2023; Vasiliev and Greenwood 2021). For instance, in Hokkaidō (Japan), the rising temperatures led to alterations in the phenological phases of various living species, hampered the mutualistic relationship between bees and the other elements of the ecological system (Kudo and Ida 2013). In North Dakota (USA), the transition from grassland to soybean was particularly detrimental to honey production and bee health, possibly because of pesticide contact (Smith et al. 2021).

Italy is no exception to the global phenomenon of pollinator decrease. Many studies monitored aspects of beekeeping, such as the health status influenced by numerous factors, including the availability and quality of agricultural lands near the hives (Porrini et al. 2016). More specifically, the risk of contamination from multiple insecticides and fungicides applied to farm landscapes is highlighted (Tosi et al. 2018). In addition, several studies focus on the current pests such as *Varroa destructor* Anderson & Trueman, 2000 (Panini et al. 2019; Bava et al. 2023) or *Vespa velutina* Lepeletier, 1836 (Bertolino et al. 2016; Pusceddu et al. 2019).

However, a limited number of studies have focused on beekeepers in Italy. A couple of studies focused on the management of small hive beetle (Salvioni and Champetier 2022; Salvioni and Cerroni 2023), Cerri et al. (2022) inquired Italian beekeepers about the severity of *V. velutina*, and Mancuso et al. (2020) provided evidence of the efficacy of total brood removal to fight *V. destructor* according to interviewed beekeepers. A study investigated the perception of beekeepers in Piedmont (NW Italy) concerning climate change, finding that NW Italian beekeepers observed the impacts of severe weather events and adapted to limit the climatic adverse effects (Vercelli et al. 2021). Finally, Whitaker (2023) has addressed the well-being stemming from the caring and interdependent relationship between beekeepers, their bees, and the surrounding landscape in the Central Italian Alps. The current study aims to understand better the main changes affecting apiculture and its drivers according to Ligurian beekeepers. Liguria, a small mountainous region of Northwestern Italy bordering the Mediterranean Sea, represents an exciting field of research for the (increasing) importance of beekeeping (Hearn and Dossche 2016) and the peculiar characteristics of the territory. The large, forested areas could represent a positive resource for beekeepers. Still, they are mostly abandoned chestnut groves (infilled by shrubs or arboreous species forming a close canopy, a challenging environment for blooming—may be helpful for the honeydew honey but there is no evidence) or newly formed woods that have replaced fields, meadows, and wood pastures rich in herbaceous and melliferous species (Fontefrancesco et al. 2022; Cevasco and Moreno 2015).

The specific objectives are to:

- preliminarily understand the Ligurian beekeeping sector characteristics (e.g. number of bee hives, main types of honey produced, years of activity);
- document the local perceptions of climate change impacts, their drivers among Ligurian beekeepers, and possible adaptation strategies.

Materials and methods

Study area

Liguria is a north Italian region inhabited by 1.5 million people (ISTAT 2023). It is mainly characterised by a Mediterranean climate with dry and warm temperatures during summer (Csa), according to Koppen-Geiger (Peel et al. 2007), while few inner areas are classified as Cfa with no dry season and warm summers. Almost 80% of its territory is mountainous, reaching 2200 m a.s.l. Around 73% of the regional surface is covered by forest (of which 30% are chestnut patches) (ISTAT 2020). Tourism is the leading economic sector and is developed along the coastline (Fig. 1).

Climate analyses reveal that more rainy autumns, but drier springs, summers, and winters, resulting in the period 1981–2010 drier than the previous period 1961–1990 (ARPAL 2013). Moreover, the annual minimum temperature increased in 70% of the Ligurian climatic stationsduring the period 1981–2010, compared to 1961–1990 (ARPAL 2013). Similarly, the annual maximum temperature increased in 55% of the analysed climatic stations in 1981–2010, compared to 1961–1990 (ARPAL 2013). The analysis of the Ligurian climatic data year 2022 reveals a decrease in precipitation of 53% and an increase of respectively 2 °C and 1.8 °C in the annual maximum and minimum temperature compared to the period 1961–1990 (see Table 1 of the Appendix).

Expected climatic changes in Liguria in the period 2038–2068 indicate that the provinces of Genoa and La Spezia will experience more intense and more frequent

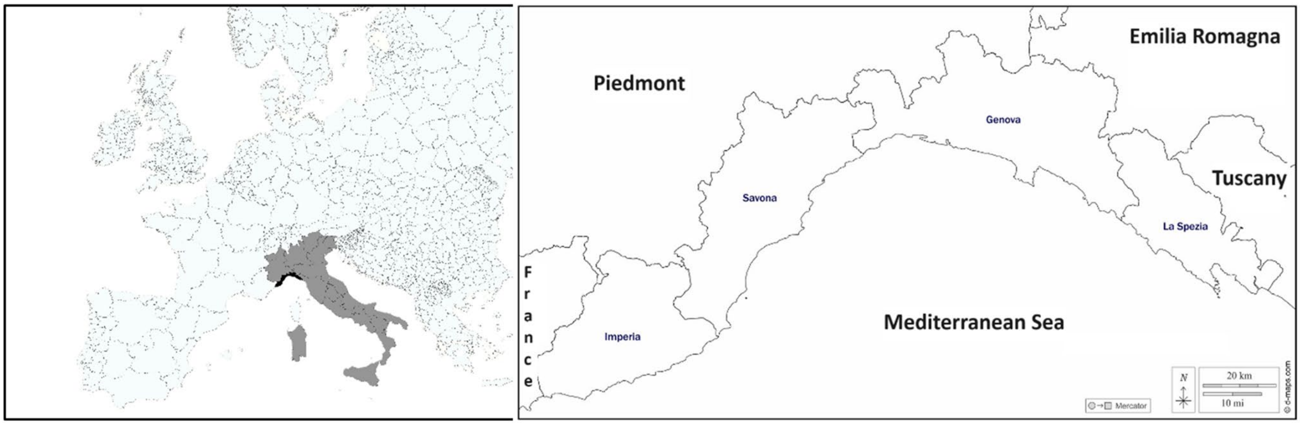


Fig. 1 Map of the study area. On the left is the position of the Liguria region in NW Italy. On the right is the location of the four provinces of Liguria

precipitations, while they will be less in Imperia and Savona provinces, with higher temperatures (CIMA 2021). Mountain areas will experience higher temperatures and less snowfalls (CIMA 2021).

These expected changes are likely to increase the challenges of beekeeping by reducing productivity (Gajardo-Rosas et al. 2022). Adaptation strategies to enhance productivity may include artificial feeding or hives relocation (Ricigliano et al. 2022; Landaverde et al. 2023).

In 2022, there were 3055 beekeepers in Liguria and 34.998 hives (BDN 2023). Among them, 965 operators performed beekeeping for economic purposes, as a primary source of income or as a supplement to other agriculture activities (BDN 2023). The remaining part consists of beekeepers who keep and conduct a small amount of hives without specific economic intentions but to obtain production for family use (BDN 2023). Between 2017 and 2022, it increased from 20.422 to 25.926 in the number of Ligurian hives, and the number of beekeepers more than doubled (from 1.360 to 3.055 units) (BDN 2023).

The honey production trends detected by the Italian National Observatory of Honey over the period 2017–2022 showed a decrease in all the most significant Ligurian honey typologies (Fig. 2).

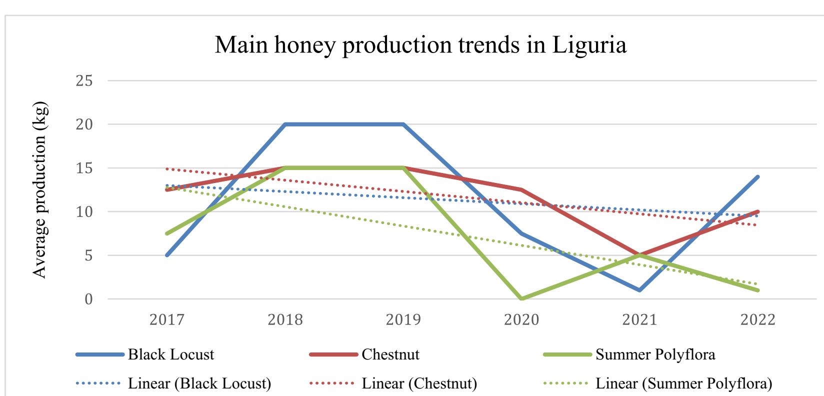
Data collection

The research was conducted between June and November 2022 in Liguria. Forty-seven beekeepers distributed all over Liguria were interviewed. The interviewees were conveniently selected through the two beekeeping associations in the area 'ALPA Miele and APILiguria'. The beekeepers were contacted by phone, explaining the aim of our research, and asking their willingness and availability to participate in it. After the first interviews, the snowball method was applied to recruit more beekeepers.

The subjects selected had to be beekeepers—professionals or hobbyists—who have been operating beehives in Liguria for at least 5 years.

Out of 60 beekeepers, 47 agreed to participate in the research. The interviews were conducted following the principles of the Code of Ethics of the International Society of Ethnobiology (International Society of Ethnobiology 2006). Before each interview, prior and free informed consent was

Fig. 2 Main honey production trends in Liguria (2017–2022). Authors' elaboration on National Observatory of Honey data



obtained. Notes were taken in a notebook. The interviews were conducted in Italian and occasionally in the local dialect (Ligurian) in each of the four provinces of Liguria. A detailed dataset of the interviewees is available in Table 2 of the Appendix. The interviewees were asked to reflect on melliferous flora and the observed changes in their beekeeping activity (see Table 3 of the Appendix).

Data analysis

Interview notes were transcribed in anExcel file according to anonymised codes of interviewees. For each anonymised code, we included the following information: years of experience in beekeeping, production area, number of hives owned, melliferous species of productive interest exploited, narratives related to changes. We performed the textual analysis of each narrative coding it according to the LICCI tree (https://www.licci.eu/licci-tree/licci-tree.svg). The LICCI tree is a tool to classify climate change-driven impacts developed within the ERC-funded project LICCI in 2020. As an example, according to the LICCI tree, in the narrative 'In the last years, climate has changed a lot. The main problems are cold and very rainy springs, especially in the last 4 to 5 years. Moreover, there is a steep drop in temperatures and temperatures are very high until late winter', we identified four LICCIs, namely (1) changes in the mean temperature in a given season; (2) changes in the mean rainfall in a given season; (3) changes in the intensity/strength of cold waves; (4) changes in temperature fluctuation. All these LICCIs belong to the Atmospheric system. LICCIs 1, 3, and 4 belong to the temperature subsystem and specifically to seasonal temperature, temperature extremes, and mean temperature respectively. LICCI 2 belongs to the subsystem precipitation and more specifically seasonal precipitation. We organised the results based on the most cited LICCIs. In the text, the beekeepers are referred to according to their code, as in Table 2 of the Appendix.

Results

Characteristics of Ligurian beekeeping

The interviewees have been beekeepers for an average experience of 19 years (ranging between 5 and 70 years), managing an average of 79 hives (ranging between five and 600).

The interviewees mentioned 41 melliferous species their bees harvest for producing honey. Each beekeeper had an average of almost four different types of honey. The most common was polyflora, produced by 44 farmers, followed by chestnut (*Castanea sativa* Mill.; $n=37$) and acacia (*Robinia pseudoacacia* L.; $n=32$) (Table 1).

Beekeepers' perceived changes in bee and melliferous flora behaviour and productivity

Interviewees reported 121 observations of change related to the bees and the beekeeping corresponding to six LICCIs (Table 2). Almost all the beekeepers ($n=46$) noticed changes in bee behaviour and productivity. Furthermore, 18 farmers noticed changes in the frequency of parasites and predators affecting the honeybees, explicitly referring to *V. destructor* and *V. velutina*. Nine beekeepers noticed a difference in the number of breed colonies.

Beekeepers observed that such changes regarding bees are deeply related to changes in the melliferous flora (52 observations), referring to five LICCIs. Among them, 26 beekeepers indicated a shift in the melliferous plant nectar productivity, and 18 mentioned a change in the flowering time. Generally, beekeepers feel disoriented concerning these changes. 'The rules of nature are changing, and we are completely losing track of the plants in the area; every year is unpredictable'. The producer specified that depending on the year, he can produce monoflora or polyflora honey 'because the blooms depend on ever-changing seasonal changes' [Bk38].

These two subsystems (beekeeping and terrestrial flora) are deeply affected by changes in the atmospheric system which represent a main driver for the changes in the life system, and limitedly in the physical system (Table 3 and Fig. 3).

Climatic drivers of change

The five most cited drivers of changes in Ligurian beekeeping belong to the the atmospheric system. Specifically, two belong to the precipitation subsystem (increased length/duration of the drought, and changes in the predictability of frost events), two to the temperature subsystem (changes in temperature fluctuation and changes in the timing of cold waves), and the last one involves the subsystem of seasons (changes in the timing of seasons). Here we are reporting each of these drivers detailing (a) how exactly they impact beekeeping, (b) examples, and (c) coping and/or adaptation strategies.

A summary of the atmospheric trends affecting Ligurian beekeeping is reported by Bk1: 'In recent years, the climate has changed significantly. The main problems are cold springs and very rainy, especially in the last 4–5 years. The temperature drops dramatically. However, until late winter, we experience very high temperatures'.

Increased length of the drought

Over half of the interviewed beekeepers (59% $n=27$) indicated an increased length of drought periods. Drought

Table 1 List of honey typologies and melliferous species mentioned by our interviewees

Typology of honey according to the bee-keepers (with English translation)	Scientific name of the plants visited by bees	Botanical family	Nr of beekeepers producing this honey
Millefiori *Polyflora*	*Acer* spp.	Aceraceae	44
	Arnica montana L	Asteraceae	
	Borago officinalis L	Boraginaceae	
	Clematis vitalba L	Ranunculaceae	
	Cornus mas L	Cornaceae	
	Crataegus monogyna Jacq	Rosacee	
	Crocus biflorus Mill	Iridaceae	
	Cytisus spp.	Fabaceae	
	Dittrichia viscosa (L.) Greuter	Asteraceae	
	Gentiana ligustica R.Vilm. & Chopinet	Gentianaceae	
	Glaucium flavum Crantz	Papaveraceae	
	Lavandula stoechas L	Lamiaceae	
	Ligustrum vulgare L	Oleaceae	
	Malus spp.	Rosaceae	
	Medicago sativa L	Fabaceae	
	Narcissus spp.	Amaryllidaceae	
	Onobrychis viciifolia Scop	Fabaceae	
	Origanum majorana L	Lamiaceae	
	Prunus armeniaca L	Rosaceae	
	Prunus persica (L.) Batsch	Rosaceae	
	Prunus spinosa L	Rosaceae	
	Pyrus spp.	Rosaceae	
	Rhododendron spp.	Ericaceae	
	Rosa canina L	Rosaceae	
	Rubus idaeus L	Rosaceae	
	Salvia spp.	Lamiaceae	
	Trifolium spp.	Fabaceae	
Ailanto *Ailanthus*	*Ailanthus altissima* (Mill.) Swingle	Simarubacee	5
Corbezzolo *Strawberry tree*	*Arbutus unedo* L	Ericaceae	3
Castagno *Chestnut*	*Castanea sativa* Mill	Fagaceae	37
Agrumi *Citrus fruits*	*Citrus* spp.	Rutaceae	1
Erica *Heather*	*Erica arborea* L	Ericaceae	22
Edera *Ivy*	*Hedera helix* L	Araliaceae	7
Ciliegio *Cheery tree*	*Prunus avium* (L.) L *Prunus cerasus* L	Rosaceae	3
Acacia *Black locust*	*Robinia pseudoacacia* L	Fabaceae	32
Rovo *Brumble*	*Rubus ulmifolius* J.Presl & C.Presl	Rosaceae	3
Rosmarino *Rosemary*	*Salvia rosmarinus* Spenn	Lamiaceae	1
Tarassaco *Dandelion*	*Taraxacum* sect. *Taraxacum* F.H.Wigg	Asteraceae	3

Table 1 (continued)

Typology of honey according to the beekeepers (with English translation)	Scientific name of the plants visited by bees	Botanical family	Nr of beekeepers producing this honey
Timo *Thyme*	*Thymus* spp.	Lamiaceae	1
Tiglio *Linden tree*	*Tilia cordata* Mill	Malvacee	4
Melata *Honeydew*	Obtained from various species	-	18

Table 2 Local indicators of climate change impacts observed by Ligurian beekeepers and the associated number of reports. *Adapted from the LICCI tree to the beekeeping context

System	Number of reports
Life system*	**173**
Beekeeping	***121***
Changes in bees' productivity (e.g. honey)	46
Changes in bee behaviour	45
Changes in the frequency of parasites in honeybees	18
Variation in the number of swarms or nuclei in apiaries	9
Changes in the timing of honeybee mating or reproduction	2
Changes in the quality of honeybee products (e.g. honey)	1
Terrestrial flora	***52***
Changes in the productivity of wild plant species (without further specification)	26
Changes in wild plant species' flowering time	18
Changes in the species composition of vegetation	4
Changes in the abundance of wild plant or fungi species stated as invasive	2
Changes in the abundance or density of wild plant species	2

affects bees, especially by reducing the availability of nectar (Fig. 3). A beekeeper with 70 years of experience explains the complex picture: 'The bees are starving today because they have no nectar to collect; everything is dry. […]. Today, there is no more water, and even the bees do not know where to go to drink' [Bk29]. A beekeeper provided an example of the impact of the drought on a melliferous plant: 'Ivy blooms in September and plays an essential role as a colony escort in the final period of the hot season, but this year production has fallen to zero because it suffered too much from the drought' [Bk10]. Similarly, in scorching and drought summers, *Metcalfa pruinosa* Say, 1830 does not correctly develop, resulting in a drop or missed harvest of honeydew honey, as a beekeeper from Imperia province reported.

According to our beekeepers, one of the bees' coping strategies in the face of drought is not to lay eggs. 'If there is no fodder outside, the bees take precautions and adjust with what is coming in. They invest in new brood according to the income and external impulses' [Bk7].

Beekeepers have started adapting in two ways. Most commonly by introducing artificial syrup feeding: 'The drought has reduced the presence of nectar, and the bees find it difficult to feed themselves, so syrup feeding has also become a major expense' [Bk16]. Some beekeepers started reducing the number of hives: 'I am decreasing more and more the number of hives because the bees, due to the constant drought of the last few years, could not find enough nectar. For about five to six years now, the lack of water in the period of plant development has led to them having less nectar or, in extreme cases, not flowering at all' [Bk5].

Changes in temperature fluctuation

Fifteen beekeepers noticed a change in temperature fluctuations, which is strictly related to changes in the mean temperature in a given season (mostly referred to as milder winters, colder springs, or hotter summers) mentioned by ten beekeepers.

Such changes affect both the bee behaviours and the melliferous flora. The temperature influences the degree of activeness of bees in a certain period. For instance, a beekeeper explained, 'Today, 24 October 2022, it was 19 °C!

Table 3 Drivers of local indicators of climate change impacts observed by Ligurian beekeepers and the associated number of reports

System	Number of reports
Atmospheric system	**153**
Precipitations	***64***
Changes in the length/duration of drought	27
Changes in the predictability/variability of frost events	13
Changes in the amount of rainfall in a given season	9
Changes in the temporal distribution of rainfall	4
Changes in mean rainfall (not further specified)	3
Changes in the spatial distribution of snowfall	3
Changes in the intensity/strength of rainfall (not further specified)	1
Changes in the predictability of rainfall	1
Changes in air moisture/humidity	1
Changes in the amount/intensity/strength of dew	1
Changes in the amount/intensity/strength of frost	1
Temperature	***59***
Changes in temperature fluctuations	15
Changes in the timing of cold waves	14
Changes in the mean temperature in a given season	10
Changes in the frequency of hot/warm days	6
Change in the intensity/strength of cold waves	4
Changes in the variation of temperature between the years (interannual variation)	3
Changes in the temperature during the night	2
Changes in the intensity/strength of heat waves	2
Changes in the intensity/strength of extremely hot seasons	1
Changes in the frequency of days with extreme temperatures	1
Changes in sunshine intensity	1
Seasons	***22***
Changes in the timing (onset or end) of seasons	11
Changes in the length/duration/disappearance of seasons	8
Changes in the predictability of seasons	3
Air masses	***9***
Change in the intensity of storms (not further specified)	2
Changes in the frequency of hailstorms	2
Change in the frequency of storms (not further specified)	1
Changes in the intensity of windstorms	1
Changes in the number of windy days	1
Changes in wind patterns (not further specified)	1
Changes in wind strength or speed	1
Physical system	**3**
Freshwater physical system	***2***
Changes in river/stream water flow, volume, level, and/or depth	1
Changes in freshwater abundance/availability (not further specified)	1
Terrestrial physical system	***1***
Changes in wildfire frequency	1

10 years ago, it might have been 4/5 °C at this time. These high temperatures stimulate the bees to work, and, at this time, the brood should be few and far between, but instead, it is voluminous. However, this is a problem because the bees go out in the warm weather to look for nectar and pollen, but in our area, there is nothing now, and so, having returned home empty, they use up their stocks' [Bk2]. The unusual temperature fluctuations also affect the melliferous flora by delaying or earlier the flowering season or reducing its productivity in terms of nectar: 'In May 2022, the temperature

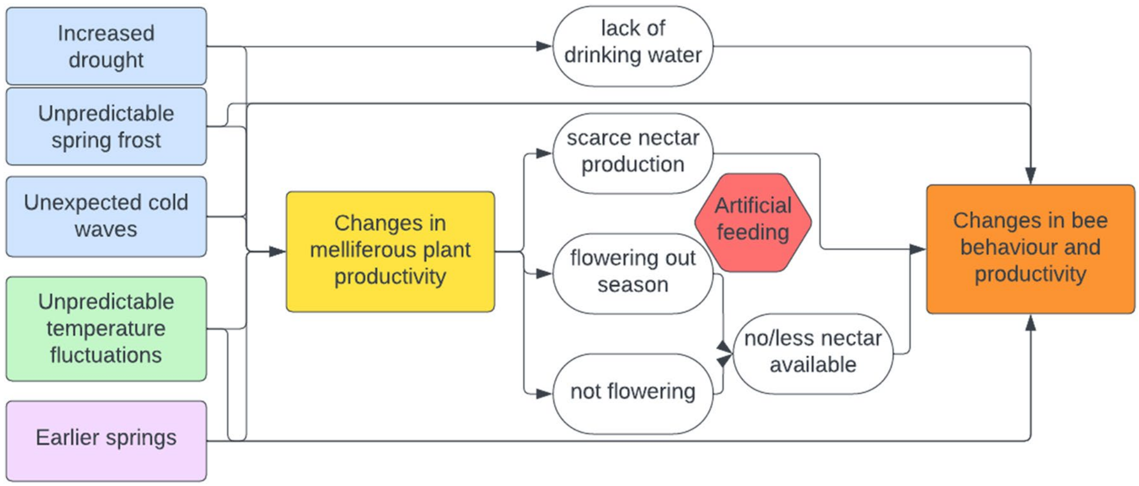


Fig. 3 Relationship between main changes observed by beekeepers and their drivers

stayed at 16 °C for some 40 days. The black locust flowers did not have nectar, but the bees were ready to collect it. Therefore, we were forced to feed them with syrup' [Bk18].

Coping strategies by bees include the use of their stocks, which is avoided by beekeepers by integrating bees' diets with artificial syrup feeding.

Changes in the timing of cold waves and changes in the predictability of frost events: increased frequency of late spring frosts and cold waves

Fourteen beekeepers indicated changes in the timing of cold waves, and 13 changes in the predictability of frost events: 'sudden frosts in recent years have become increasingly frequent'. These events especially refer to spring which, according to the beekeepers, is characterised by increased cold waves and frost events, which are more typical of the winter season. Indeed, some beekeepers argue that the increase in temperatures in recent years resulted in milder winters, but with a sudden drop in temperatures in late Spring, which are very detrimental to honey production. These cold spells were quite unusual until few years ago and are very detrimental event for beekeeping activity. These events affect both the well-being and productivity of the bees and the melliferous plants. Beekeepers observed bee die-off or weakness when temperatures suddenly drop. Abrupt cold and frost events compromise nectar production to a halt, also compromising subsequent secretion.

For instance, a producer in the province of Imperia reports: 'In the spring period, there should be an increase in laying and a vigorous activity of collecting pollen for nutrition, but the bees go out and find nothing because the cold has burnt everything, and so the queen goes into brood block' [Bk15]. With regard to the melliferous flora, a beekeeper from Genoa province stated, 'This spring has been marked not only by repeated frosts but also by strong currents that have dried out the flowers' [Bk1]. Due to the increased frequency of these events, in some inner areas of Liguria, beekeepers reported the suspension of production of black locust (*R. pseudoacacia*), honey between 2018 and 2022 due to cold spells that affected nectar production.

'The once stable Spring has been frustratingly followed by ten years of rainy and unstable springs. This instability damages the harvest because the main honey harvest is in Spring' [Bk7]. Indeed, these late cold waves and frost events have a heavy economic impact on beekeepers because they affect profitable productions such as black locust and require artificial syrup feeding which has also an economic cost: 'By now, syrup feeding is routine, and so the risk of producing honey with exogenous sugar in it is very high. If the bees have used up their stocks at the end of the winter and a month of continuously cold weather falls upon us, we have to administer many litres of syrup, an expense that affects the annual yield' [Bk18].

Changes in the timing of seasons: earlier spring season

Eleven beekeepers reported an early arrival of the spring season: 'Flowering times 'arrive much earlier than in past decades' is a common observation among the interviewees. This driver is often coupled with other drivers: 'Early springs together with sudden cold spells affect nectar production and consequently that of honey' [Bk37]. This driver affects especially the melliferous flora and consequently the bees.

As an example, in the province of La Spezia, a beekeeper reports that black locust production has ended after the end of May for over 20 years; currently, even before mid-May, honey production is already at its peak. Spring moving up also results in earlier summer blossoming: 'The timing is changing. I started this business in 2003 and have always seen the chestnut blossom in July; this year, in June, it was already in flower' [Bk30]. Multiple sudden unexpected changes make hard for farmers to synchronise the beekeeping activity with the flowering cycles, developing colonies with many foragers apt to harvest the nectar at the right flowering time [i.e. Bk36].

Also in this case, the most common adaptation strategy to overcome the lack of synchronisation between bees and melliferous flora availability includes artificial syrup feeding.

Other atmospheric changes affecting beekeeping

We recorded nine reports of beekeepers referring to increased wind intensity since 2019. The wind not only acts negatively on the melliferous flora by drying it out and reducing its nectar secretions but also hinders the flight of bees trying to return to the hive laden with nectar and pollen. A beekeeping technician says: 'The bad weather has affected the plants in full bloom, but the adverse effects are also attributable to the wind, which has hampered the bees' foraging activity' [Bk44]. A beekeeper with 45 years of experience claimed: 'I cannot produce any more because the wind is too violent' [Bk13]. The owner of a farm in the Beigua Geopark says: 'It had never happened that in the summer the animals needed to be fed to survive, but in Sassello, the sea wind did much damage' [Bk11], referring to a coping strategy.

Another aspect concerns the increased intensity of rainfall which affects the melliferous flora and as a consequence, the bees. Heavy rain compromises the natural flowering pattern, severely reducing the nectar and pollen production available to bees. 'The heavy rainfall that increases and concentrates in short periods causes disasters. The flowers lose all the nectar they had until then' [Bk43].

Furthermore, intense rainfall also results in floods. One of the beekeepers decided to stop the movement of hives in 2021 after 36 of his hives were swept away by a significant flooding event.

Non-climatic drivers of change

The climatic changes are not the only drives of changes observed by the Ligurian beekeepers. The interviewees identified three possible anthropogenic factors behind the decline in beekeeping production: the spread of alien species which affect both melliferous plants and bees, the spread of pesticides, and the abandonment of small-scale (mountain) agriculture.

In the last decades, four animal and one plant species significantly impacted Ligurian beekeeping. Among the animals, beekeepers reported about the mite *V. destructor* and the insects *V. velutina*, *Dryocosmus kuriphilus* Yasumatsu, 1951 (Chestnut gall wasp), and *M. pruinosa* (Citrus flatid planthopper). *V. destructor* was reported by all the interviewees as they carried out anti-varroa treatments two to three times a year to prevent bee mortality. 'By now', reported a producer, 'we must get used to it and learn to live with it. I apply all the necessary treatments, but I still find parasites at the bottom of the hive' [Bk16]. As proof of the fact that varroasis is endemic throughout Liguria, a beekeeper from Imperia narrated: 'During the first two years of activity I wanted to do beekeeping without intervening on the bees and therefore on their health; until 20/30 years ago varroa was not a common problem as it is now. So, every year for three years, I lost 90% of my hives. At that point, I realised that it was necessary to do treatments with oxalic acid' [Bk17]. Therefore, the widespread adaptation strategy included the application of oxalic acid to prevent bee losses.

A more recent alien noxious species, *V. velutina* (Asian hornet), affects bee behaviour**.** The main issue is that the foragers, terrorised by the presence of the Asian hornets, can no longer go out to collect nectar and pollen, so they consume the stocks and, when they run out, find themselves in food stress. According to our interviews, the distribution of *V. velutina* is uneven across the region: 'In my area [Imperia province], the situation has reached extreme levels. Normally, the hornets arrived in my apiary at the end of July, and the fight continued until August. This year, at the beginning of June, because of the high temperatures, there was an invasion, and they started hunting full out; families were already suffering, and much harvest was lost. These hornets hunt by positioning themselves in front of hives and eating the foragers. If you have a honeycomb, you cannot take it away from the family because you starve them' [Bk22]. The impact of noxious alien species is coupled with the climatic changes described above. Also, in the Imperia area, particularly its coastal area: 'The *V. velutina* situation is serious because the excessive heat last winter and Spring meant that this animal, which comes from subtropical areas, could start its activity and biological cycle much earlier. On 7 February 2022, the first nest with the queen had already been spotted, which had never happened before. What is frightening is that it has moved to higher altitudes, 800/1000 m a.s.l. in significant numbers and eastwards, in the Savona area. Until 2020, there have never been any reports in the province of Savona' [Bk25]. None of the interviewees from the province of Genoa detected the presence of this Hymenoptera.

Interviewees reported that collaboration and connections between beekeepers and people involved in agriculture who belong to the same community are crucial in this context, and strategies have been created to communicate and report the presence of colonies. 'Thanks to the involvement of local people and reports, as well as training activities, 50 nests were removed last year'.

D. kuriphilus is a Hymenoptera which damages local chestnuts by significantly decreasing their blossoms and, thus, honey production.

A beekeeper in Genoa province, with more than 20 years' experience in the sector, reported that in 2013, the gall caused the chestnut tree's nectar secretion to fall to zero and added: 'The nectar secretion took years and years to recover and has never returned to previous levels. Those were abysmal years. When the first launches of the antagonist were made, the situation gradually improved. Various control attempts have been tried in managing the gall using resistant varieties and chemical products'.

Coping strategies were adopted at the regional level through biological control with a specific parasitoid: *Torymus sinensis* Kamijo, 1982. This strategy helped to sustain chestnut trees, but, according to our beekeepers, the use of T. *sinensis* does not represent security: 'Production is uncertain, and the graphs fluctuate from year to year; the antagonist does not always manage to prevail over the chestnut gall wasp, there are years when one win and years when the other wins' [Bk21].

After describing the alien species that are an obstacle to beekeeping, one species that is an advantage deserves a closer look: *M. pruinosa*. This insect is crucial for producing honeydew honey, which is the final fruit of the bees' collection of the sugary secretions of *M. pruinosa*. It absorbs the sap to obtain the nitrogen necessary for its development and then discards the liquid, mainly of sugars. These sugary secretions, like small droplets that dot the plant's leaves, attract bees just as much as nectar from flowers. Nevertheless, the beekeepers noticed that although *M. pruinosa* plays a positive role in beekeeping-related production, serious damage to horticultural crops and orchards is demonstrated. So a natural enemy (*Neodryinus typhlocybae* Ashmead, 1893) has been reared and released. A beekeeper states that since the introduction of the antagonist in the area, honeydew production has decreased dramatically, but 'the *Metcalfa* has not only suffered from the presence of its enemy, but it has also had to reckon with the drought of recent years, which is not beneficial for its survival. This year, I came close to 10 kg of honeydew per beehive; I used to produce 50 kg' [Bk46].

The beekeepers reported specific changes related to introducing a specific melliferous plant in addition to the no-longer invasive black locust. *A. altissima* has expanded for many years in marginal areas with poor soil morphology, such as railway embankments or roadside verges. The abandonment of agriculture allowed the growth of this invasive species: 'a negative species'. Its excessive and uncontrolled presence develops essences that damage the production of monofloras and polyflora. The takeover of *A. altissima* reduces the diversity of other species, thus changing the landscape where honeybees harvest and the honey they produce.

A second driver of changes in Ligurian beekeeping is the spread of pesticides. A small proportion of Ligurian beekeepers blamed the use of plant protection products and unsustainable agricultural techniques for the weakening and sometimes disappearance of bee colonies. Many are aware that: 'The use of plant protection products kills colonies'. However, the peculiar characteristics of the territory have hindered agricultural production to the extent that large quantities of pesticides are used.

One of the coping strategies adopted concerns changes in the movement of beehives. The owner of a farm in Genoa province recounts that she used to practice moving bees in an area. Still, in recent years, this area was no longer available/accessible as she observed high bee mortality there, attributable to poisoning by pesticides used for wheat cultivation in the neighbouring areas [Bk27]. A third driver of changes in Ligurian beekeeping is the abandonment of traditional agricultural practices that occurred since the end of WWII and had a profound impact on the landscape and, more specifically, on melliferous vegetation composition. When farmers managed the land, the bees had 'much more to forage'.

Finally, chestnuts were a crucial plant for the territory and its beekeeping. 'Chestnuts used to represent bread for us Ligurians', says a producer with 22 years of experience [Bk43]. 'The elderlies always had terracing with fruit trees and chestnut trees that were well cared for. Now, it is all abandoned. No young people desire to live in the countryside, and the institutions do not help either; they do not support the farms in the mountains. The few remaining woods of chestnut groves are all abandoned and subject to continuous deterioration. Chestnut grove abandonment is a problem for beekeepers, although many have not yet realised this'. A high percentage of producers attribute the decline in chestnut honey production precisely to the abandonment and cessation of landscape management, not only in terms of quantity but also quality: 'Until 40 to 50 years ago, we had whole expanses of chestnut trees, but with the abandonment of the fields, the weed vegetation is predominant. So, the end product is different because the floral component is different' [Bk26].

Not only that, but this also includes nectar and pollen production, which will be lower in weak plants. **'**No one wants to take care of chestnut groves anymore, and in this way, knowledge is lost. I, for one, and I admit this regretfully, cannot manage it, prune it and take care of it. It is a complex practice, and doing another job, I do not find the time to take care of it. The institutions should understand that it is not just a forest [Bk43]'.

In the Fontanabuona Valley, a beekeeper mentioned: 'In recent years, we have seen with our own eyes that abandonment leads to the development of more competitive plants, and so the chestnut tree dries out and is replaced by ash or hornbeam' [Bk38]. Species such as ash and hornbeam are not important essences in beekeeping because they have minimal nectar production.

Discussion

Our research reveals three main results. First, beekeepers especially noticed changes in bee productivity and behaviour and melliferous flora productivity. Second, climate change, especially drought, is a significant driver of changes in beekeeping as it affects both bees and melliferous plants. Third, climate change is not the only driver of change but other drivers, namely alien species, pesticide spread, and abandonment of small-scale agriculture, also concur synergistically.

Before discussing the results, we want to highlight the high environmental and thus climate variability of the Liguria region, which may determine different impacts of climate change on beekeepers. For instance, in summer 2022, the Savona province recorded a significant increase in seasonal precipitation (+65%), while Genoa province recorded a decrease (−81%) (see also Appendix Table 1). Therefore, while the experiences and perceptions of the interviewees may partially depend on their locations in Liguria, we focused our results and discussion on common trends observed by most of the interviewed beekeepers.

Observations of reduced productivity and changes in bee behaviour by beekeepers have been recently reported by several colleagues in Italy (Vercelli et al. 2021), in Europe (Van Espen et al. 2023), and elsewhere in Chile (Gajardo-Rojas et al. 2022), Ethiopia (Kumsa and Gorfu 2014), Mexico (Magaña Magaña et al. 2016), and Benin (Armand Paraïso et al. 2012). However, changes in melliferous flora were less noticed or studied, with quick mentions in Italy (Vercelli et al. 2021) and a deeper look which reported the cutting of melliferous plants and forest clearing to be perceived as the first threat to apiculture by Balkan beekeepers (Šarić et al. 2023). Outside Europe, beekeepers of El Salvador reported a decrease in flora density and nectar availability (Landaverde et al. 2023) and changes in composition due to land use changes in Costa Rica (Galbraith et al. 2017).

Climate is a significant driver of bee well-being (and productivity), which aligns with several other researchers. In the Mediterranean basin, bee behaviour and productivity are deeply influenced by weather conditions, including temperature, humidity (which we capture through the subsystem precipitation), and wind (Gounari et al. 2022). Similarly, in the Balkans, only 3.6% of the beekeepers did not perceive or weakly perceive climate change impact as a threat to beekeeping (Šarić et al. 2023). Moreover, significant regional disparities have been highlighted, with Southern European beekeepers experiencing a tenfold likelihood of being heavily affected by climate change impacts compared to Northern Europe (Van Espen et al. 2023). Based on beekeepers' perceptions and analytical data, several researchers agree that climate change is not the only factor affecting beekeepers. However, it is often combined with other elements, such as pesticides and other pollutants (Šarić et al. 2023). Noxious alien species include pests such as *V. destructor* and *V. velutina*, whose effects on bee health are well-perceived by beekeepers (Pusceddu et al. 2019; El Agrebi et al. 2022; Bava et al. 2023). Alien melliferous plants appear at high density and dominate the flora in invaded sites (Bjerknes et al. 2007), strongly affecting the quality of honey production and, eventually, bee behaviour (Stout and Morales 2009). Finally, connected with the other mentioned drivers, changes in the agricultural landscapes are noted by beekeepers in different contexts, yet available literature mainly refers to deforestation (Galbraith et al. 2017; Šarić et al. 2023). Contrarily, natural reforestation and small-scale agricultural abandonment (especially of the chestnut orchards) were mentioned in Liguria as major detrimental points for beekeeping. Historical ecology research documents the loss of biodiversity in Ligurian ancient grasslands and wood pastures due to the abandonment of mowing and grazing, including populations of *Arnica*, *Gentiana*, and *Narcissus* (Gabellieri et al. 2020; Lagomarsini 2013; Cevasco 2007), which are protected and melliferous plants mentioned by our interviewees.

We documented a significant adaptation strategy among beekeepers: applying syrup feeding to overcome periods where nectar is unavailable. This is a common strategy in different contexts; nevertheless, the cost of such syrup is often high for the beekeepers, which makes beekeeping less/little economically viable yet needed. However, weather unpredictability hampers beekeepers' capacity to cope with and adapt to the observed changes.

Beekeepers are uniquely positioned to maintain and support pollinators, which are crucial to ensure global environmental and human health. Through the sensitivity of the bees, beekeepers can interpret changes and provide precious information for shaping local policies.

We know that reversing the current climate change requires significant efforts from all of us and long-term strategies. Nevertheless, environmental governance often needs help to listen to the voices of beekeepers, and it could instead help shape effective policies for ensuring pollinator health (Maderson 2023). Currently, Ligurian policies support beekeepers by funding material and immaterial tools to reduce the impact of *V. destructor* and climate change, also promoting the movement of hives in the territory. Beekeepers can request technical assistance, workshops, and seminars through regional funds through their associations. While these measures are undoubtedly beneficial, landscape planning sensitive to the needs and requests of beekeepers can further contribute to their adaptation to the impacts of climate change and address the significant reduction/elimination of pesticides harmful to pollinators, as well as supporting small-scale agriculture and grazing as a way of maintaining a diverse landscape which provides fodder for pollinators.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10113-024-02242-3.

Acknowledgements We are deeply grateful to all the beekeepers who share their time and observations with us. Special thanks to the LICCI team for developing the project 'LICCI. Local Indicators of Climate Change Impacts' (FP7-771056-LICCI), which inspired this research.

Author contribution GM and AP conceptualised and supervised the research. FR collected and organised the data. GM analysed data and prepared a first draft with significant contributions from FR. MP and RC contributed to the first draft with their specialised knowledge. All authors revised, edited, and approved the final draft.

Funding Open Access Funding provided by Universitat Autonoma de Barcelona.

Data Availability The data used to support the findings of this study are included within the article.

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