Attuning local and scientific knowledge in the context of global change: The case of heather honey production in southern France

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A B S T R A C T

This paper addresses the assumption that combining scientific and traditional knowledge is a promising means to elaborate alternative ways of adapting to ongoing changes that are compatible with local values and priorities. To do this, we analyze a case study of the production of heather honey in southern France. Production of this very particular type of honey, which was formerly massively exported to Germany, has dramatically declined over the two last decades. In this study, we examined the respective views of different stakeholders — beekeepers producing heather honey, specialists of heather honey production, scientists — about the specific environmental, economic and social drivers of this decline in the sector of Mont Lozère, an important region of heather honey production located in the heart of the Cévennes National Park in southern France. From our results, we conclude that information held by these three different stakeholders is congruent and complementary. Together, their perspectives provide a more coherent picture of the drivers of change affecting the production of heather honey than any of the perspectives taken alone. We suggest that the consilience of these distinct kinds of expertise can foster the rehabilitation of this particular honey, whose production can provide benefits that are not only economic and ecological, but also in terms of perpetuating a biocultural heritage.

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1. Introduction

It is nowadays widely admitted that the preservation of biological diversity can no longer ignore the cultural diversity that accompanies it — and sometimes safeguards it. Like the biotic resources they depend on, human societies are increasingly impacted by globalization, a dramatic driver of vulnerability of resources and societies to environmental change that decision-makers must come to grips with. However, rural societies are accustomed to confronting and responding to social and ecological change (including for instance, climate variability), adjusting their adaptive strategies accordingly. They may thus have underestimated sources of resilience against the challenges imposed by globalization. In this context, sociocultural approaches to analyzing biodiversity in the face of environmental changes are arousing increasing interest.

These approaches focus on two main subjects of study. The first focuses on traditional ecological knowledge, i.e., the knowledge, beliefs, traditions, practices, institutions, and visions of the world that are elaborated by local communities as the result of their interactions with their biophysical environment (Toledo, 2002); the second emphasizes perceptions, i.e., the ways local people identify and interpret observations and concepts (Byg and Salick, 2009; Vignola et al. 2010 and Phillips, 2014). The use of traditional ecological knowledge is often recommended to reduce knowledge gaps in conservation and local perceptions are increasingly mobilized to achieve more effective ecosystem-based management (Berkes et al. 2000; Bérard et al. 2005; Biro et al. 2014).

Local perception and the related emergence of traditional ecological knowledge are generally linked to a particularly salient component of the environment, which is likely to shape the relationship between humans and their surrounding nature. We consider here the extended landscapes that adopt a remarkably pink color in summer over areas as large as several square kilometers in the Mont Lozère, France. This sudden shift in color is caused by the mass blooming of heather (Calluna vulgaris (L.) Hull, Ericaceae), a small but very extent shrub. Heather is known to
produce a great quantity of nectar (Crane, 1976; Roberts, 1994; Beekman and Ratnieks, 2000), thus justifying beekeeping for the production of heather honey as a prominent extractive activity on this landscape. Heather nectar is the source of a very atypical honey, with unique organoleptic properties. Recently, heather honey beekeepers noticed a significant drop in honey production by bees. They are uncertain about the possible reasons for this decline, although many evoke changing climatic conditions. We explore various hypotheses in this paper, such as changes in climate, in pastoral practices. In addition to trying to determine the real causes of heather honey decline, we will also consider how the knowledge and practices of the local beekeepers have evolved and adjusted to ongoing change.

Besides continuously providing various goods (honey, wax, propolis, pollen, royal jelly, venom . . . ) and environmental services through the pollination of countless angiosperms (Delaplane and Mayer, 2000; Johnson, 2010; Michener, 2000; Vaissière, 2002), Apis as well as stingless honeybees serve as sentinels of the environment and indicators of ecosystem health, in ways that no longer need to be demonstrated (Clément, 2009; Dounias, 2009; Haubruge et al. 2006; Kevan, 1999). Honeybees tirelessly alert us about subtle environmental alterations that we are unable to perceive directly by less sensitive to high and sensitive to tiny modifications of their environment is certainly not specific to bees, but no other social insects have elaborated such uninterrupted and faithful relationships with humanity over the past 15,000 years. One of the reasons for continuing interest in investigating local beekeeping practices is the persistence today of a wide gradient of bee domestication. Honey-hunting societies throughout the humid tropics continue to explore natural ecosystems in search of wild honey, reminding us that honey has been for ages the only source of sugar immediately available from the wild (Anselot 1980: Crane, 1999; Paterson 2008). At the same time, in another part of the world, Californian beekeepers transport their rented frame hives of an introduced species on huge trucks for transhumance throughout vast mono-cropped and pesticide-saturated agro-industrial landscapes. In between these two extremes, there exists a continuum of beekeeping practices on honeybees and on the equally social and honey-producing stingless bees (Meliponines) that are diversely semi-domesticated. Several forms of beekeeping practices may even coexist in the same territory, mobilizing different sets of knowledge and know-how, and differing in their effects on local biodiversity.

Local beekeepers all possess empirical knowledge about bees and their productions (Dounias and Michon, 2013). Through their regular observation of the activity of bees, traditional beekeepers have elaborated an extensive knowledge of local climate variability and change as part of their traditional ecological knowledge, which is acquired and transferred through generations (Berkes et al. 1995, 2000). They could play a prominent role in monitoring the incidence of global change on local biodiversity, in places where this incidence is insufficiently assessed by the scientific community (Dounias, 2009). This local ecological knowledge is a lever for community resilience to respond to the multiple stressors of global environmental change (Gómez-Baggethun et al. 2013). Eliciting local ecological knowledge and perceptions of traditional beekeepers should help to analyze environmental crises about which bees can warn us. It is notable that in most attempts to apply traditional ecological knowledge as indicators of ecosystem health and environmental change, data concern animals, whereas plant species figure much less frequently (Biro et al., 2014). The originality of our study is the investigation of a triple interaction among beekeepers, honeybees and heather. Ecological interactions between species are often more threatened than species themselves (Janzen, 1974), and thus may be more sensitive indicators of ecosystem health and environmental change.

The goal of this paper is to address the assumption that combining scientific and traditional knowledge is a promising means to elaborate alternative ways of adapting to change that are compatible with local values and priorities (Boissière et al. 2013). To do this, we investigated the production of heather honey in southern France. This very particular type of honey, which was formerly massively exported to Germany, has been dramatically declining over the past two decades. We identify the specific environmental, economic and social drivers of this decline in the sector of Mont Lozère — a spot of heather honey production that is located in the heart of the Cevennes National Park in southern France (Fig. 2) — and use this case study to compare (i) the knowledge of beekeepers who produce heather honey, (ii) the knowledge of specialists of heather production, and (iii) the scientific literature. We then examine whether the combination of these diverse kinds of expertise opens pathways that would contribute to the rehabilitation of the heather honey chain.

2. Material and methods

2.1. Heather and heather honey

Heather, Calluna vulgaris (L.) Hull (Ericaceae) (Fig. 1) is the single species of its genus. It is a small shrub 20–100 cm in height that is found throughout Europe. Heather grows preferably on poor and acid soils and grows best in full sun (Rayner, 1913; Gimingham, 1972; Webb, 1986, 1998). Leaves are scaly, small (2–4 mm long), sessile (Fig. 1) and densely intricate over four rows. Flowers are 3–4 mm long and are grouped in racemes; they are pale purple to pink and the corolla is bell-shaped (Webb, 1986) (Fig. 1). Heather blooms from July to October depending on the region, and may produce such considerable amounts of nectar (Roberts, 1994; Beekman and Ratnieks, 2000) that Crane (1976) classifies it as highly bee-foraged: a single bee colony is said to produce 100–200 kg of honey per visited hectare.

Among all the different types of honey that are produced throughout Europe, heather honey is certainly the most atypical. Its unique flavor and its physical properties make it quite special. Its water content is very high, up to 23%, whereas values in other types of honey never exceed 19–20% (Huchet et al., 1996). Heather honey has an unusual viscosity that complicates honey extraction: it is a thick gel under static conditions, but it becomes a liquid on shaking (Fig. 1). Its viscosity is highly variable: it is said to be 20% (Huchet et al., 1996). Heather honey is also unusual. This study focuses on the sector of Mont Lozère, in the French territorial administrative unit called ‘département de la Lozère’. This sector was chosen because sources detailed of information were available about the recent local history of the production of heather honey. Mont Lozère (Fig. 1) is also part of the ‘central core’ (‘zone cœur’) of the Cevennes National Park and is located in a Natura 2000 site (Fig. 2). In these protected sites, questions about the link between the conservation of biodiversity and the
maintenance of human activities are of great importance. Knowledge on traditional beekeeping in chestnut trunks to produce a peculiar and local honey (Lehebel-Péron et al., 2015), the traditional exploitation of chestnut forest to produce chestnut flour, and extensive agro-pastoralist practices linked to a space that was recently recognized by UNESCO as a Mediterranean agro-pastoral
Cultural Landscape, are concrete and successful examples of past incorporation of local ecological knowledge into agro-environmental management plans within the Cevennes National Park.

The ‘Mont Lozère’ is a granitic summit that is surrounded by mountains bearing schistose soils and delimited on the north and south by two valleys (Roux et al. 2005). Soils of Mont Lozère are predominantly acid (pH = 4.5 to 5) and poor in mineral elements, and are thus particularly suitable for the establishment of large heather populations. Throughout this study, the production of heather honey in the sector of Mont Lozère was compared to that in several other parts of France (see after) where large populations of heather are present and similar honey is produced.

2.3. Acquisition of information

Data collected about heather and the production of heather honey were obtained by three methods: (1) semi-directive interviews of beekeepers, (2) semi-directive interviews of specialists of heather production in the sector of Mont Lozère, and (3) scientific information originating from different sources and covering various aspects: meteorological and geographical data, as well as published scientific literature from different disciplines.

As a first step, a telephone call was sent to 119 beekeepers inviting them to participate in this study. These targeted beekeepers were scattered in the 4 French administrative regions where heather occurs (in low to high abundance) — a region is the higher level of administrative unit of this country. A total of 36 beekeepers responded (participation rate: 30.3%) and this study is based on their responses. The 36 responding beekeepers are all located in the four main French administrative regions producing heather honey (Fig. 2). Eighteen of these beekeepers are located in the Languedoc-Roussillon region, and 9 of them set up or formerly set up their hives in the sector of ‘Mont Lozère’. The 18 other beekeepers came from three other regions: 6 from Aquitaine, 6 from Midi-Pyrénées and 6 from Auvergne (Fig. 2). The relatively small sample sizes for these three regions suggest the need for caution in interpreting the results for them. The larger sample size for Languedoc-Roussillon reflects the greater extent to which this region is known and used by beekeepers for hive displacement (transhumance) during summer to take advantage of the heather blooming season.

Interviews of beekeepers lasted 30–60 min and were performed face-to-face (n = 20), by phone (n = 8) or by e-mail (n = 8) between mid-May and Mid-December 2011 by the same interviewer, following a semi-directive method providing a single framework of basic questions (Mestre and Roussel, 2005). Beekeepers were invited to respond spontaneously and their identities were kept anonymous a posteriori in the analysis of their responses. After posing a series of questions aimed at characterizing the interviewee’s beekeeping activity, the interviewer alternated (1) closed questions (‘yes’ or ‘no’ response) about the relationship between the impact of human activities and environmental changes and the decrease of the production of heather honey, and (2) open questions aimed at obtaining free-form comments about this relationship. Citations given in extenso (between inverted commas) in the results section originated from these comments. On the basis of preliminary studies, we grouped answers in four distinct categories of environmental and contextual factors: (1) climate change, (2) decline of grazing combined with closure of landscape, (3) sanitary status of bees and (4) three kinds of human activities (controlled fires, forest plantations, air and soil pollution).

No other explanatory factor was cited by beekeepers. Beekeepers were authorized to cite more than one explanatory factor.

As a second step, we conducted face-to-face interviews of six people that we defined, ex post facto, as ‘specialists of heather’ and knowledgeable about heather production in the sector of Mont Lozère, following the same method and conditions described above. These individuals were not personally or professionally connected so this category of ‘specialists’ does not formally exist outside of the context of this study. Three of these persons are staff members of the Cevennes National Park, one is a researcher specialized in the ecology of heather, another is a staff member in the agriculture division of the ‘département de la Lozère’, and the last one is a staff member in the Ecomuseum of Mont Lozère.

As a third step, we compiled published scientific papers on Mont Lozère and extracted literature from various databases providing information related to the five previously cited environmental and contextual factors that potentially explain declining heather honey production. Climate data covering Mont Lozère were obtained from the MétéoFrance meteorological station of ‘Pont-de-Montvert’, a village situated within the sector of Mont Lozère. Information about the decline of grazing, the closure of landscapes and controlled fires originated from the database of the Cevennes National Park.

The first part of the results section concerns analysis of the decline in production of heather honey, while a second part deals with how global change may explain this decline in heather honey production. The first part is mainly based on the responses of the 36 beekeepers interviewed, whereas the second part compares the knowledge of beekeepers producing heather honey, that of specialists of heather production, and the information available in the scientific literature.

2.4. Data analysis

All data were analyzed in R 2.12.0 software (R Core Team, 2013). We used a Mann–Whitney test to compare the mean annual honey production before and after the year 2000. We also used post hoc Kruskal–Wallis tests for multiple comparisons.

3. Results

3.1. Decline in production of heather honey

Twenty-seven out of the 36 interviewed beekeepers (75%) evoke the existence of a ‘golden age’ of heather honey, when production was much higher. This period is situated before 1970 by 14% of them, and between 1970 and 2000 by 61% of them. Eleven percent of the interviewed beekeepers affirm that such a golden age never occurred and 14% have no opinion on this issue (no idea, or admitting insufficient experience to give a confident answer). However, 92% of the interviewed beekeepers agree that there was a decrease in the production of heather honey during the period 1990–2000. We thus considered the year 2000 as a dividing line marking the beginning of the decline and distinguish hereafter two periods: before and after 2000.

When produced quantities of heather honey were recorded or can be estimated from the beekeeper’s own experience over several years (n = 19), we asked each beekeeper to indicate a minimal and a maximal value of production of heather honey per hive and after 2000. Median values of reported production per hive before and after 2000 were authorized to cite more than one explanatory factor.

As a second step, we conducted face-to-face interviews of six
reported from their own experience that “the old price (before 2000) was higher than today”. All beekeepers indicate Germans as the main buyers of honeyer for the period 1970–1990. Most of them also express disappointment about “a low rate of commercialization within France during this period”. This general statement is confirmed by the comparison of the country in which interviewed beekeepers posted their production of heather honey: 70.6% was sent to Germany before 2000 (n = 17) whereas 64.7% of this honey is now being sent within France since 2000 (n = 17) (χ² = 4.25; p < 0.04). Interestingly, the decline in production of heather honey was accompanied by relocation of trade inside France. Some beekeepers evoke new procedures aiming to “improve the local trade by the creation of different administrative sorts of cooperatives (‘Groupement Agricole d’Exploitation en Commun’ or ‘Groupement d’Intérêt Economique’)”. In the sector of Mont Lozère, “export to Germany was facilitated by the regular presence of German ‘brokers’ (locally called ‘courtiers’) who negotiated directly with honey producers. Heath honey was shipped to Germany after being stored in 300 kg barrels (locally called “füts”). Some interviewed beekeepers continue to be astonished by the abrupt collapse of exports to Germany and deplore the sudden silence by their former German customers. In order to understand the reason(s) for this shift, we tried to approach 15 German importers. Only one of them eventually replied, writing that “French heather honey has become steadily too expensive. In the present time, my importation from France corresponds to less than 1% of my sales, whereas this percentage 10 years before was still about 10%”. Interviewed beekeepers stress that “the Germans now obtain heather honey from other European countries (Spain, eastern European countries) at a cheaper price and in larger quantities”. The French producers did not increase their prices; the Germans simply found other more advantageous sources of honey.

Nevertheless, the social organization of heather honey producers as well as producer perceptions and practices have also changed recently and may have contributed to this shift. Most beekeepers remember that this production was an economic godsend before 2000, but they state this only from memory. Nineteen percent of the interviewed beekeepers argued that they stopped producing heather honey because the tiny quantities obtained were not worth the investment, in terms of effort and costs. Economic profit is too hazardous to maintain because “the costs of hive renting and transporting to transhumance sites both increased steadily and are no longer compensated by the decreasing quantity of honey produced”. In addition, “the extraction of the heather honey requires both the use of a particular set-up (the tear drop machine, see introduction) and supplementary operations compared to the production of other kinds of honey, thus more time and money investment”. Most interviewed beekeepers also evoked a sanitary risk specifically tied to the production of heather honey; “they prefer ignoring this honey production and letting it to bees”. The negative effects of parasitic Varroa mites on honeybee colonies are maximal during the end of summer and beekeepers accordingly perform a sanitary treatment during this period. This treatment must be postponed up to mid-September if heather honey is produced: “producing this honey increases related sanitary risks, which have become prohibitive in the current context that combines economic difficulties and colony collapse disorder”. Lastly, most interviewed beekeepers spontaneously affirmed that “the production of heather honey is highly erratic from one year to another as well as from a beekeeper to another, without any obvious explanation”. Curiously, only 14% of the interviewed beekeepers recognize that such unpredictability also occurred during the ‘golden age’ of heather honey.

32. Exploratory factors for the decline in heather honey production

Socio-economic drivers along the restructuring of the German supply chain are to be considered among these exploratory factors and all actors agreed that they negatively impacted the production of heather honey in France. It was treated as an admitted fact and was accordingly excluded from the interviews. In this part, we investigated how environmental and contextual factors may also explain this decline by analyzing the responses of the three types of actors. As explained above in the material and method part, we selected four environmental and contextual factors linked to global change that could potentially explain the decline in production of heather honey: (1) climate change, (2) decline of grazing combined with closure of landscapes, (3) declining sanitary status of bees and (4) three kinds of human activities (controlled fires, forest plantations, air and soil pollution). A recapitulation of these explanatory factors is provided in Table 2.

The main factors evoked by beekeepers to explain declining heather honey production differed among the four considered regions. Beekeepers spontaneously evoked more than one explanatory factor in 94.4% of cases in Languedoc-Roussillon (n = 18), in 66.7% of cases in Auvergne and Midi-Pyrénées (n = 6 in each region) and in 50% of cases in Aquitaine (n = 6). Climate change was cited as the main factor in Languedoc-Roussillon, as a main factor equal to other factors in Auvergne and Midi-Pyrenees, and as a secondary factor in Aquitaine. The category ‘direct human actions’

Table 1 Recapitulative results of linear regressions between years and precipitations and temperature. R² is the value of the linked test of regression; confidence intervals of P value:***, P < 0.001; **, P < 0.01; *, P < 0.05; NS: non significant.

<table>
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<td>December</td>
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Fig. 3. Variation in the price of heather honey during the period 1987–2008. This information is established from invoices paid to the same beekeeper (P. Thomas) in the Mont Lozère. Prices from 1987 to 2002 are converted to euros.
was evoked as the prior driver in Aquitaine. In all four regions, bee health was ranked as the least important of the four factors.

3.2.1. Climate change

All beekeepers agreed on the importance of significant rainfall before heather blooming to maximize both the number of flowers and the quantity of nectar. Meanwhile, 83% of all interviewed beekeepers (89% of beekeepers from Mont Lozère) indicated climate change as an explanatory factor, and they emphasized changes in temperature, rainfall and snow cover. They pointed out the increased frequency of drought, the decreased duration of snow cover and an overall increase in weather unpredictability. A large majority of beekeepers thus report a negative impact of fluctuating weather conditions on the production of heather honey.

All the interviewed heather specialists also cited increasing variation of weather conditions, with an increased frequency of drought periods combined with a decreasing duration of snow cover. They also reported a tight correlation between soil humidity and the total quantity of nectar produced (number of flowers x quantity of nectar produced per flower).

The fact that the production of nectar increases right after rainy days has been known by scientists for a long time (Bonnier, 1879) because nectar induction depends directly on some abiotic environmental factors (soil humidity and temperature) (Melin, 2002) and weather (Hocking, 1968; Southwick et al., 1981). Moreover, heather may reproduce vegetatively as well as sexually (Whittaker and Gimingham, 1962). Seed germination occurs generally in May and requires a temperature range of 17–25 °C and a relatively high level of soil humidity (Noirfalise and Vanesse, 1976). Climate change may greatly influence the reproduction of heather: under heavy drought conditions, the plant seems to postpone germination to the following year (Noirfalise and Vanesse, 1976).

Analysis of the weather data recorded in the meteorological station of Pont-de-Montvert shows a significant (Anova; \( P = < 0.001 \)) increase in average annual temperature between the two periods 1970–1980 and 1980–2000. Differences between the two periods were also significant for monthly averages in March, April, May, June and August (Tukey tests: \( P = < 0.01 \) for 1970–1980 and 1980–2000), but were null for July (Tukey tests: \( P > 0.10 \) for 1970–1980 and 1980–2000) (Table 1). Additional weather data (monitored in the meteorological station of Vialrosse, also situated in Mont Lozère) similarly reported a significant increase of temperature of 0.7 °C during the 1981–2007 period (Didon-Lesco and Martin, 2004). In this latter station, these authors also noted high temperatures and low precipitation during the period comprised between May and September 2003. 2003 was a very bad year in terms of production of heather honey. In addition, and for the same period 1981–2007, the thawing of snow occurred much sooner (March instead of May) and, since 1989, snow has been falling in lesser quantity than expected according to old standard values (Didon-Lesco, 1996). Lastly, no clear significant difference was detected for rainfall, although great annual variations were noted.
(Didon-Lesco and Martin, 2006). A more recent study performed in Mont Lozère and in other sites throughout Languedoc-Roussillon (Ruffault et al., 2013) confirms an increase in temperature, a contraction of the period of snow cover, and a decrease in rainfall.

### 3.2.2. Decline of heather populations due to grazing and landscape encroachment by woodlands

Fifty-six percent of the interviewed beekeepers (67% of those located in Mont Lozère) indicated grazing decline as one of the factors explaining the drop in heather honey production. All of them agree on a direct relation between a decline of grazing and an encroachment on landscape by woodlands. All interviewed specialists pointed out grazing decline and landscape encroachment as joint explanatory factors. Landscape encroachment in Mont Lozère is mainly due to the development of pine trees, whose effects are twofold: a fragmentation of the open spaces in which heather populations preferably establish; and an increase in the surface occupied by pine woodlands in replacement of ancient shrub populations, including shrub heather. However, specialists also stress the contribution of the modification of agricultural practices; one specialist even suggested that this might be the major driver of overall regression of heather throughout Europe. In Mont Lozère, cows have massively replaced sheep, and this conversion has been detrimental to the growth of heather for two reasons: (i) the regeneration of heather is minimal in the presence of cows, which browse this plant less than do sheep or goats; (ii) heather is highly sensitive to soil compaction by stamping, which is more pronounced with cows. As a consequence, heather populations grow older, with a lower level of regeneration; this in term leads to a decline in nectar production.

Scientific data confirm the ongoing scarcity of heather populations in Mont Lozère, as well as in western Europe generally. In Mont Lozère, between 1970 and 1999, the proportion of surface occupied by landscapes extensively covered with heather out of a total surface of 329.22 km² decreased from about 24% to about 15% (equalling a 38% loss); for the same period, shrubland proportion decreased from about 31% to about 24% (equalling a 22.5% loss); forest proportion increased from about 45% to about 62% (equalling a 38% gain) (Fig. 4). In other words, the surface occupied in 1999 by heather dominated landscapes regressed by 38% in barely 2 decades. Over the past 30 years, the large populations of heather in Mont Lozère have progressively given place to pine woods (Lecus, 2001; Lhuillier, 2000) (Fig. 5). This dramatic conversion of Mont Lozère landscapes is primarily a consequence of the reduction in pastoral activities, which led to the encroachment of pioneer tree species, mainly scot pine (*Pinus sylvestris*) and mountain pine (*Pinus uncinata*) on formerly open habitats (Loiseau and De Montard, 1998). The persistence of ecological habitats tied to heather would require the maintenance of both sheep grazing and extensive agricultural practices (Picouet et al. 2004). The contraction of threatened plant populations often resulted from the abandonment of traditional land use, causing an ensuing of litter accumulation, an encroachment by shrubs and trees, and a spread of invasive species (Baur et al. 2006; Middleton, 2012). Furthermore, changes in climatic conditions may also influence the maintenance of heather populations by increasing interspecific competition. A simultaneous increase in temperature and in the frequency of drought favors plant species that are adapted to more xeric conditions — such as the wavy hair grass (*Deschampsia flexuosa, Poaceae*) — at heather’s expense.

### 3.2.3. Sanitary status of bees

Forty-two percent of interviewed beekeepers (44% of beekeepers in Mont Lozère; the other 66% of them having no opinion on this question) point out that the declining sanitary status of bees could explain the drop in heather honey production. They evoke the exposure to various pesticides (but not in Mont Lozère, where pesticides are almost absent), the low size of bee population inside hives during heather blooming seasons, and mainly the pressure exerted by parasitic Varroa mites, which reaches its maximum at the end of summer, just when bees are busily occupied in gathering heather nectar. Beekeepers can no longer treat the hives in that context. None of the heather specialists expressed an opinion on this issue, which is outside their domain of competency.

Scientific data globally confirm the detrimental impact of various pathogens on honey production in general. Under the Mediterranean climate, the average quantity of honey stored by bees is 45% lower in colonies infested by Varroa destructor than in non-infested colonies (Murilhas, 2002). However, to our knowledge, no scientific source has ever reported specifically on the incidence of pathogens on heather honey production.

### 3.2.4. Direct human impact

This category is divided into three distinct subcategories of factors present in the four considered regions: controlled fires, forest plantations and pollution. Aquitaine is the only region where some beekeepers evoked direct human impacts. Four beekeepers incriminated the use of a local device called ‘rouleau landais’ that is intended to cut shrubs (and, incidentally, heather); two others cite the decrease of water reserves in soils which would be detrimental to heather; finally, one beekeeper considered urbanization to be responsible for the destruction of ancient sites of heather.

#### 3.2.4.1. Controlled fires

Among interviewed beekeepers, 53% (n = 19) expressed an opinion about the role of controlled fires in explaining the diminished production of heather honey (the others were without opinion). Among these beekeepers who expressed an opinion, 47% declared controlled fires to be negative factors, whereas the other 53% perceived this factor as a positive one.

The heather specialists interviewed affirmed that controlled fires have beneficial effects only under particular conditions, depending on the frequency of fires and on the agricultural practices that are carried out after fires. The optimal interval between two controlled fires was estimated at around 5 years; at longer intervals, the excessive temperature of burning of large quantities of biomass could destroy dormant seeds in soil seed banks. Furthermore, certain species in Mont Lozère, such as the Pyrenean broom (*Cytisus oromediterraneus*), are better competitors (developing more rapidly) than heather after fires. Accordingly, controlled fires need to be followed by sheep grazing in order to regulate the young shoots of competitors of heather and favor the

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**Fig. 4.** Variation of surface (in km²) occupied by three habitats (extensive landscape with heather, shrublands and forests) in the Mont Lozère between 1970 and 1999 (Lhuillier, 2000).
more slowly growing and developing heather.

Scientific data concur with views of heather specialists in documenting fire frequency and agricultural practices required post-fire as factors determining whether the impact of controlled fires on heather honey production is beneficial. The optimal interval between controlled fires varies from 5 to 8 years because heather requires 3–5 years to fully regenerate, and an extra 2–3 year period before completely covering the ground (Noirfalise and Vanesse, 1976). Seed germination is stimulated by fires only if fire intensity (which depends on accumulated biomass) does not exceed 160 °C at ground level; beyond this temperature threshold, fires will destroy the pool of dormant heather seeds (Whittaker and Gimingham, 1962). Furthermore, grazing after fires appears necessary to prevent colonization by pioneer species of shrub or trees (Pakeman et al. 2003; Britton et al. 2003). In Mont Lozère, sheep grazing after fires is required to favor heather and prevent the dominance of Pyrenean broom (Dumez, 2010).

3.2.4.2. Pine forest plantations. 22% of interviewed beekeepers (11% of beekeepers in Mont Lozère) cite an increase in forest plantations as a cause of the regressive production of heather honey, since it is directly linked to a reduction of the surface occupied by heather. All specialists of heather agree that the expansion of pine forest plantations, which were established during the 1960s–1970s, is accompanied by a reduction of the surface occupied by heather. Scientific data fully support this assertion, notably in the Massif Central, a mountainous region that includes Auvergne, Mont Lozère and a part of Languedoc-Roussillon (Direction Régionale de l’Environnement, 2007). The reduction of the surface occupied by heather is certainly a result of the combined expansion of forest plantations and closure of landscape that is encouraged by the reduction of sheep grazing.

3.2.4.3. Air and soil pollution. None of the beekeepers mentioned pollution as an important cause of the decline in heather honey production. Only one out of the six interviewed heather specialists pointed out that air pollution is likely to alter composition of the soil and to be incidentally detrimental to heather; nitrogen, sulfur and nitrate inputs in soils via precipitations (in snowfall as well as rainfall) act as fertilizers, whereas heather prefers poor and acid soils.

Scientific data show that nitrogen emissions in the area have increased and that this increase is linked to the consumption of fossil fuel and to various inputs from agriculture (Galloway and Cowling, 2002). Increased emissions explain why nitrogen concentrations in soils in the area have increased significantly (Barker et al. 2004). Availability of nitrogen intervenes (i) as a limiting factor for certain plants, including heather, which are known to prefer poor soils (Tamm, 1991); (ii) as a factor inducing change in the composition of plant communities (Pitcairn et al. 1991); and (iii) as a factor influencing ecosystem functioning (Matson et al. 2002). Berendse et al. (1994) even argue for a strong causal relationship between the increase of nitrogen in soils and the decrease of heather populations. More generally, Ericaceae are prominent in nutrient-poor soils and become scarce when nutrient concentrations increase, incidentally favoring their replacement by grasses and other herbaceous plants (Diemont, 1996).

4. Discussion

The main result of this study is the demonstration that information from the three sources we considered—local beekeepers,
‘specialists’ of heather and scientists — was congruent and complementary, together providing a more coherent picture of the drivers of change affecting the production of heather honey than would have been given by each source of information alone (Table 2). The seven major aspects emerging from this synthesis are the following:

1. An increasing tendency in the world of conservation is the better integration of local knowledge, reflecting a continuum between academic specialists and various local actors (Marchenay, 2005). Here, the congruence and complementarity of information reported reflect convergent points of views between beekeepers and specialists of heather production. Answers obtained from the beekeepers interviewed located in Mont Lozère do not differ from those given by beekeepers of the other regions. Besides the fact that they express more concerns about the issue of landscape encroachment by woodlands, which appears more acute in Mont Lozère than in any other area the beekeepers in Mont Lozère are quite representative of the whole community of heather honey harvesters throughout the country. The heather ‘specialists’ interviewed unanimously concurred with all the factors of decline that were put forward by the beekeepers, and emphasize two additional factors. The first is pollution (evoked by only one member of this category), which can hardly be assessed without formal quantified data. The second factor is bee health, but heather specialists are cautious in evoking this factor. The opinions they express reflect elusive feelings rather than firm statements. Moreover, scientific data globally corroborate the factors advanced by the beekeepers and heather specialists and provide complementary explanations, though most of these data do not originate from the sites that are specifically addressed in this study (Bérard et al. 2005; Boissièere et al. 2013). All these points provide a convergent view about the decline in the production of heather honey.

Views of actors are slightly more divergent about the role of Varroa infestation and controlled fires as explanatory factors this decline. The incidence of Varroa infestation on heather honey production is also a poorly documented and acute issue. The importance that beekeepers attach to this issue and the lack of scientific studies specifically addressing the impact of Varroa on this type of honey production both suggest the interest of further study of the sanitary status of bees in the context of community-based revalorization of the heather honey sector. Beekeepers could play a leading role in a participatory research initiative to better document and counterbalance the deleterious impact of Varroa on heather honey production. Otherwise, fire is the only factor for which no consensus emerges among the beekeepers concerning its importance as a cause of declining heather honey production. When beekeepers express an opinion on controlled fires (as almost one-half of the beekeepers did), voices are equally divided between those who estimate that such controls have a positive effect and those who perceive them negatively. This is a domain where local expertise of the beekeepers could be strengthened and refined through a reinforced dialogue with scientists, whose conclusions about the role of fire and of post-fire agricultural practices on the maintenance of heather populations are much less equivocal.

Besides these convergent points and others slightly divergent, there are several other points to consider in the understanding of decline in the production of heather honey. Firstly, there was a significant correlation between factors cited as most important by the beekeepers interviewed and their immediate or short-term incidence, as already shown elsewhere (Berkes, 2004; Bérard et al. 2005; Byg and Salick, 2006; Boissièere et al. 2013). Less important factors whose incidence may be less immediate or less tangible arise in a longer and less tangible run are much less frequently mentioned as causes of decline in heather production. Our results concerning pollution, a factor that was never cited by the interviewed beekeepers, illustrates this point quite convincingly (Barker et al. 2004). The degree of tangibility of the facts also influences their perceived relevance as drivers. Temperature, snow cover and drought are tangible indicators of climate change. Similarly, the allocation of exploitable lands is a tangible indicator of landscape encroachment, and so are personal practices to address stubble burning, as well as formal experience in managing plantations to address forestry plantations.

Secondly, nectar secretion by heather remains so far poorly documented. It is a critical issue to tackle since secretion depends on a combination of factors, some intrinsic to the physiology of the plant itself and others affected by environmental variables that influence the foraging activity of bees (Southwick et al. 1981; Seeley et al. 1991; Melin, 2002). However, although scientific data on nectar secretion would provide new insights on how these various factors influence nectar production, these data would not help estimate the role of changes in nectar secretion in the decrease in heather honey production over the past decades, since no study exists that quantified former levels (i.e., before 2000) of nectar secretion.

Thirdly, the drop in heather production in Mont Lozère is a consequence of a combination of factors, environmental, economic and social. Heather production is a unique economic activity that is geographically contained and that combines wild (heather), domesticated (bees) and socioeconomic (honey extraction technique and commercial honey production) components of a socio-ecosystem. This activity illustrates the fact that traditional human activities are deeply grounded in a specific landscape or natural environment and cannot be totally disconnected from economic drivers intervening at a broader (even international) scale (Dounias and Michon, 2013; Gómez-Baggethun et al. 2013). Assessing the embedded relevance of any given local or traditional activity requires considering jointly the social (including historical or at least diachronic), ecological and economic drivers of change in the activity. Neglecting one of these three pillars would inevitably lead to a partial, and thus inaccurate, understanding of ongoing changes.

Although undoubtedly severe, the shortage in heather honey production in Mont Lozère is not total and irreversible. The decrease in exports to Germany has led to a relocation of the sector inside a domestic market. A posteriori, the formerly massive export of heather honey to Germany sounds more like an ephemeral financial bubble than a solid and perennial market strategy. The good side of the crisis is that it encouraged the establishment of cooperative structures, which may enable beekeepers to pursue a low, yet perennial, heather production activity in Cevennes, and it simultaneously strengthened a spirit of solidarity and incited initiatives to further their mutual interest. The development of a new label ‘Cevennes National Park’, as for other products ‘made in Cevennes’, is still in progress concerning honey. The release of products with this mark of distinction should provide important support for the recent reorientation of the heather honey sector (Bérard et al. 2005). Obtaining such a brand for Cevennes honey is strongly supported by the new charter of Cevennes National Park, which aims to promote locally made honey as a flagship of natural and cultural heritage in the Cevennes, along with the preservation of heather-dominated landscapes. Nevertheless, archived data about the economic drivers of the decline of heather honey production are dramatically lacking and, in the absence of factual elements from the main German honey importers, the broad picture is so far mainly supported by the memory of beekeepers who experienced the sudden drop in exports and on their guesses regarding the causes of the collapse. The paucity of economic literature pertaining to the recent history of the heather honey trade undermines a revitalization of this trade, which could be
backed by the emerging cooperative initiatives and by a community-based regulation of resource sustainability.

The congruence and complementarity of the three considered types of knowledge have several implications for the conservation of heather patches in the context of the Cévennes National Park, as well as for the potential revalorization of heather honey production through a new marketing strategy. Firstly, the congruence of knowledge from these three sources is a major asset in the sense that each knowledge type has its own specificities and outlines, while no source contradicts either of the others. Holders of the three types of knowledge each have a specific role to play through their interactions within distinctive circles of influence or through the distinctive way each of them communicate with the same stakeholder. For instance, if we consider the Cévennes National Park, beekeepers most generally interact on the ground with the technical agents and eco-guards; the heather specialists who are solicited as external consultants are more inclined to exchange with the management board and the donors, while the scientists address their conclusions to the scientific and advisory committees. The fact that beekeepers, heather specialists and scientists share the same appreciation of the situation reinforces the legitimacy their respective roles: holding (and contributing to) a common core body of knowledge creates favorable conditions for a reliable corpus of information to be shared with a much broader range of stakeholders, reinforcing the credence attached to the circulating information that beekeepers, heather specialists, and scientists diffuse within their usual circles of influence. Secondly, the complementarity is a strong argument for enhanced communication and sharing between academic and folk sciences, not only to further investigate the many existing gaps in knowledge regarding heather biology and ecology, but also to produce a more complete body of knowledge. The creation of such a mutualized body of knowledge is essential if we are to take up the challenge of implementing a new heather production sector that is intended to be a more oriented to a domestic market and more sustainable.

5. Conclusion

Natural resources worldwide are indisputably affected by global change, which alters the environmental context of their production. These modifications are, in essence, multifactorial and require a holistic perspective to be assessed properly. The drivers of change that may impair the production of the resource are of various origins; their detection and measurement require an interdisciplinary approach and an accordingly tight collaboration between human and social sciences on the one hand, and life sciences on the other, to characterize the various ecological, economic, historical, and socio-cultural dynamics in play. Reaching this goal also requires considering other forms of expertise outside the usual circle of academic sciences and to foster dialogues between holders of different knowledge types (Braunisch et al. 2012; Biro et al. 2014). Local ecological knowledge generally provides useful information for nature conservation not only on the species studied but also about the history of their habitats and their use in the past (Berkes et al. 2000). Local producers, who are in the front line of exposure to change, have built their own vision of ongoing changes and have implemented adaptive responses that are inherent to their traditional ecological knowledge (Gomez-Baggethun et al. 2013). Other actors have acquired distinct — yet still relevant — forms of learned views vis-à-vis the resource in question and the changes that are at stake. That the dialogue between the holders of these various forms of knowledge should be encouraged appears self-evident, but still remains a pious wish when we move from good intentions to positive action. The case study detailed in this paper tries to address the assumption that combining different types of knowledge — academic and non-academic — could be a promising means to elaborate alternative paths of development that are compatible with local values and priorities (Boissiére et al. 2013). The study focused on the production of heather honey production in the sector of Mont Lozère, which is renowned as a major region for the production of this particular type of honey and that is located in the heart of the Cévennes National Park in southern France. It is only recently that agro-environment programs carried out in this protected area that is one of the most densely inhabited in France, tried to take local ecological knowledge into consideration (Crosnier, 2005). Our results clearly comes in support of community-based initiatives by showing that the information provided by the holders of each of the three types of knowledge is congruent and complementary. Combination of these views contributes to more complete understanding of the various drivers of change at the origin of the dramatic decline of heather honey production over the past two decades. A major outcome of this combination of views is that climatic factors (temperature, snow cover, drought), ecological factors (heather ecology, plant/pollinator interactions, encroachment by trees, pollution) and socio-economic factors (technology of heather extraction, market opportunities, context of National Park policy) interplay and should be addressed together. The historical context is also a key dimension to take into consideration (Berkes, 2004; Phillips, 2014). Confrontation of different knowledge types also helps to identify the major gaps in knowledge: nectar secretion by heather and sensitivity of heather honey production to Varroa mites are examples of critical issues that remain poorly understood. Considering the strong concern of the beekeepers for improving the sanitary status of their honeybees, joint efforts between beekeepers and scientists should be encouraged through more participatory action research. This confrontation of views is salutary for implementing a constructive dialogue between the various stakeholders, to give a new impulse to the heather honey sector while taking advantage of the context of its production in a protected area. The release of a new brand to support a ‘Made in Cévennes’ honey production sounds a promising way to promote an artisanal activity compatible with the specific biocultural features of the National Park, while providing solid opportunities for economic expansion and sustainable development. Implementing a community-based conservation strategy that would take advantage of the natural and cultural heritage of the National Park, as a means to achieve both economic development and landscape preservation, is the ultimate challenge facing the rehabilitation of local honey production. Local beekeepers are favorably placed to detect tangible alterations of honeybee activities with regard to ongoing changes. As sentinels of the environment, bees alert us about dramatic degradations of our landscapes, and local beekeepers are invaluable partners for interpreting the messages that bees can send us. Acknowledging the local ecological knowledge of the beekeepers is an absolute prerequisite to obtain their prior informed consent and to ensure their voluntary adherence to a community-based management initiative dedicated to heather.

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