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There's More Than One Way To Know A Bee: Beekeepers' environmental knowledge, and its potential role in governing for sustainability

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ABSTRACT

This paper explores the epistemological contradictions and complementarities of different geographies of environmental knowledge, as illustrated within the context of understanding bee health. Debates surrounding the relevance of local knowledge, whether used on its own or combined with spatially abstracted scientific understandings, have significant implications for understanding and managing the agri-environment, in which bee health is a matter of social, ecological and economic concern. Recent years have seen the development of multi-scalar policies designed to reverse the declines in honey bees and other pollinators, many of which highlight the role of beekeepers in monitoring and ensuring pollinator wellbeing. This paper uses archival analysis, interviews and participant observation to explore the defining characteristics of beekeepers' environmental knowledge, and this community's potential to help improve pollinator wellbeing. This paper notes beekeepers' practical reliance on tacit knowledge, which frequently shares some of the characteristics of Traditional Environmental Knowledge (TEK). Although their localised tacit knowledge is often combined with wider scientific study, generating spatially complex hybrid knowledge, practical experience is emphasised as key to successful beekeeping. Locally situated practice generates significant observations of factors affecting bee and other pollinator wellbeing, as well as knowledge about wider land use changes and its impact on bees. While TEK and other tacit understandings are recognised as supporting sustainability, environmental governance often struggles to successfully incorporate the insights of diverse epistemological communities whose lives are entangled with other species.

1. Introduction

Recent years have seen growing public, scientific and policy attention given to pollinator decline (Potts et al., 2015, Sánchez-Bayo and Wyckhuys, 2019). Pollinator health significantly impacts food security and biodiversity, and therefore concerns us all (Ollerton, 2017). While all pollinators are recognised as being at risk (Vanbergen and IPI, 2013), much of the focus has been on *Apis mellifera*, commonly known as the honey bee (Smith et al., 2016). Cultural, practical and scientific reasons underpin this imbalance in attentions. Humans and honey bees have a long entangled history. Beekeepers have carefully observed bees for centuries, developing a wealth of knowledge about their life cycle, behaviour, and their relationship with the wider physical environment (Crane, 2004, Walker and Crane, 2001). We find bees' productivity inspirational, and the sight of a colony's inner workings hypnotic. Bees' social behaviour enables us to keep them for honey production, pollination services, and to study various biological causes of their ill health and wider decline (Breeze et al., 2011). Bee declines leapt to widespread public attention in 2006, with disturbing accounts of Colony Collapse Disorder – a mysterious syndrome which saw experienced beekeepers lose their colonies for no obvious reason (Vanegas, 2017). This triggered intense scientific research into these dramatic declines, leading to increased knowledge, and concern, about health challenges to bees and other pollinators (Le Conte et al., 2010, Pettis and Delaplane, 2010). It is now widely accepted that pollinators face a panoply of challenges, including habitat loss (Naug, 2009), pests and pathogens (Alaux et al., 2010; Wilfert et al., 2016), pesticides and agrochemicals (Goulson et al., 2015, vanEngelsdorp and Meixner, 2010), loss of forage (Decourtye et al., 2010) and climate change (Brown et al., 2016, Marshman et al., 2019).

To address these challenges and ensure the wellbeing of pollinators, and, by extension, ourselves, there have been a broad range of local and national pollinator policies, designed to improve the environment for pollinators (Hall and Steiner, 2019, Vanegas, 2017). Many of these policies explicitly acknowledge the role of beekeepers in monitoring and ensuring pollinator wellbeing (Maderson and Wynne-Jones, 2016). This

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emphasis on a coalition of stakeholders, and an active incorporation of multiple communities and knowledges, is indicative of recent calls for more inclusive environmental governance which recognises and engages with tacit and hybrid knowledges (Hill et al., 2020, Rathwell et al., 2015). The contribution of such knowledges to supporting sustainability is noted in studies of Traditional Environmental Knowledge (TEK) (Gomez-Baggethun et al., 2013) and the tacit / hybrid knowledge of farmers (von Glasenapp and Thornton, 2011), fishers (Boonstra et al., 2019), pastoralists, (Oteros-Rozas et al., 2013), hunters (Nadasdy, 2007) and other communities whose lives are closely entangled with their physical environments, and the myriad species who share these spaces (Joa et al., 2018, Reyes-Garcia et al., 2019).

While there are growing calls for more inclusive governance, which actively engages with diverse forms of knowledge (Tengo et al., 2014, Tengo et al., 2017, Hill et al., 2020), there is a limited understanding of the defining characteristics of such tacit knowledge, and how it can contribute to understanding, and resolving, environmental challenges. The relationship, and frequent tensions, between local and broader conceptualizations of the natural environment has significance within geography and science and technology studies, as well as practical implications for environmental governance (Morris, 2006; Scott, 2008). Localised environmental understandings are replete with meanings which motivate a sense of multispecies connection and a human willingness to defend localities against real and perceived threats (Jasanoff, 2010). Epistemological differences impact how local knowledge forms are perceived and utilised in public spheres (Turnhout et al., 2020), with hegemonic preferences given to knowledge generated through formal science (Lam et al., 2020). For beekeepers' knowledges to significantly impact pollinator protection efforts, it is important to understand the defining epistemological characteristics of their hybrid knowledge, its generation and dissemination, and how these characteristics can make a unique contribution to sustainability. Epistemological and political barriers to broader engagement with their distinctive environmental insights must be acknowledged, as failure to address power differentials between different communities curtails the transformative potential of multiple forms of environmental knowledges within policy spheres (Harrison, 2008; Robbins, 2006). This article presents an exploration of multiple empirics, illustrating the unique, hybrid environmental knowledge of beekeepers. It provides evidence of how beekeepers apply this knowledge in their practice, and their assessment and monitoring of environmental conditions, and their suitability for pollinators. This article argues that beekeepers' environmental knowledge contains epistemological characteristics of both hybrid and Traditional Environmental Knowledge (TEK) systems, both of which are recognised as having considerable potential to enrich environmental understanding and management. However, the beekeeping community's 'amateur' status amongst the wider bee health stakeholder coalition, coupled with tensions between values ascribed to localized environmental understandings, versus spatially abstracted notions of scientifically valid objective knowledge, limit the full capacity of their knowledge to contribute to significant transformations to support pollinator wellbeing.

Section Two will discuss TEK and hybrid knowledge, noting the defining characteristics and qualities of these forms of experiential learning. It will explore how this knowledge can support environmental sustainability, and how it is generated, and used, by beekeepers. Section Three will outline the research methods used for this paper. Section Four will present the empirical findings on beekeepers' knowledges. Section Five concludes the article.

2. Environmental Knowledge: Integrating and Co-Producing for Sustainability

As policy-makers work to address environmental challenges, debates are increasingly about understanding, and integrating, different types of knowledge (Fazey et al., 2014, Jasanoff, 2004, Whatmore, 2009). Discussions surrounding the politics of knowledge frequently assume distinct categories – eg, state, local, or scientific (Robbins, 2000; Scott, 2008). Such terminology can overlook the heterogeneous nature of epistemic communities and their sub-categories (Morris, 2006), as well as detract from the interrelated nature of categories, and the evolving nature of knowledge as it is iteratively co-produced through relationships within and between communities (Robbins, 2000). As knowledge evolves, the process of knowledge creation, and preferential status of particular knowledge cultures, must be considered (Tsouvalis et al 2000). A dominant emphasis on evidence-based policy assumes a higher level of veracity and reliability within data generated via universal scientific methods and prioritises such evidence to support practical decision-making (Dicks et al., 2013). However, this model is based on a particular approach to testing hypotheses within Randomised Control Trials (RCT), and generating quantifiable data (Cartwright and Hardie, 2012, Cowen et al., 2017). While appropriate for some decisions, it is not necessarily suitable for understanding and acting on environmental complexities (Saltelli and Giampietro, 2017). Current environmental challenges such as pollinator decline are wicked problems, requiring multi-agency approaches which may seem intractable (Jax et al., 2018). The IPBES note the importance of engaging with diverse communities and multiple forms of environmental understanding as a fundamental aspect of securing biodiversity and sustainability (Hill et al., 2020, Tengo et al., 2017). However, there are significant barriers to the successful integration of differing epistemologies, particularly when these knowledge forms are held by communities who are outside, or on the fringes of, dominant hegemonies (Turnhout et al., 2020, Hanspach et al., 2020, Robbins, 2006). Pollinator decline threatens biodiversity and sustainability (Brown and Paxton, 2009, Ollerton, 2017, Vanbergen and IPI, 2013). Recognising diverse types of environmental knowledge, including that of beekeepers, and applying such understandings to efforts to reverse pollinator decline, has a strong potential to support pollinator conservation schemes. The success of efforts at epistemological integration will be influenced by the capacity of schemes to overcome geographical tensions that permeate knowledge controversies, and the spatial characteristics of environmental understandings (Whatmore 2009). Constructive dialogues are necessary between local expertise, with its lived meanings and implied passions, and scientific understandings, which erase the local specificity and geographical context which is experienced and valued by individuals and communities (Jasanoff 2010). While these spatial tensions are a ubiquitous challenge to environmental governance (Scott 1998), they can be successfully addressed within efforts to amalgamate seemingly contradictory understandings of the environment; acknowledging the hybrid nature of communities' environmental understandings, and addressing the values held within these understandings, can support effective environmental governance (Robbins 2006).

2.1. TEK

Since the 1990s, there has been a growing body of research on TEK – or Traditional Environmental Knowledge (Agrawal, 1995; Berkes et al., 2000; Turner et al., 2000; Usher., 2000). Specific definitions vary, but the following is widely accepted and used within discussions of TEK:

> *TEK is the cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down in generations by cultural transmission, about relationships of living beings (including humans) with one another and their environment (*Berkes et al., 2000*, p 1252).*

While some see TEK as inherently rooted in the particular world views of its holders, and elements of spirituality (Olsson et al., 2004, Berkes, 2004) others argue that TEK's key quality is as a form of situated knowledge (Ianni et al., 2015, Ogwuche, 2012, Oteros-Rozas et al., 2013). For some, TEK's defining feature is its long-term, multi-generational association with a specific physical area (Altieri and Parviz, 2008, Knudsen, 2008). Huntington et al (2002) discuss TEK in a broad sense, seeing it as knowledge people develop through a long history of living or working in a particular area. This knowledge is not static but reflects changes in resource use patterns and other aspects of the relationship between people and their surroundings, including the influence of scientific and other forms of knowledge. Although TEK can be, and increasingly is, combined by its practitioners with formal training, and/or modern technologies (Gomez-Baggethun et al., 2013), the practical element of TEK, rooted in a particular geographical location, with its own distinctive ecosystem complexities, is a paramount feature. Decisions regarding natural resource use and management are often taken based on a fundamentally instinctive analysis of a range of factors, including weather and animal behaviour (Luo et al., 2009, Nadasdy, 2007, Royer et al., 2013).

While early writers on TEK primarily explored it in the context of remote, First Nation communities (Berkes et al., 2000; Davidson-Hunt, 2006; Nadasdy, 1999) TEK is now seen as broadly relevant to the knowledge and environmental management practices of diverse communities. TEK is present and pertinent in the environmental understanding and resource management of Italian Alpine villages (Ianni et al., 2015); Spanish transhumanists (Oteros-Rozas et al., 2013); Turkish fishing communities (Knudsen, 2008), Norwegian farmers (Wehn et al., 2018) and Louisiana coastal communities (Bethel et al., 2014). It has been identified in archival sources on the internet, which are seen as offering potential guidance to agri-environmental restoration (Burton and Riley, 2018). TEK is seen as a source of agricultural and environmental resilience, as these knowledge systems encourages sustainable ecosystem management, and emphasise constant observation and feedback learning, within the context of inherently fluid and unpredictable ecosystems (Gomez-Baggethun et al., 2013, Joa et al., 2018, Reyes-Garcia et al., 2019). TEK is not limited to static practices passed down through generations: it is used in combination with a broad range of contemporary equipment (Knudsen, 2008, Royer et al., 2013). While TEK holders frequently work with 'modern' technologies, their assessment of environmental conditions, and decision-making processes, are rooted in users' experiential, historical knowledge of their distinct physical location. First-hand experiential knowledge, linked to a particular locale, and frequently passed on via multigenerational transmission, is also a key aspect of beekeepers' knowledges (Lehébel-Péron et al., 2016, Phillips, 2014).

2.2. Hybrid knowledge

Due to its emphasis on a practical combination of tacit and more formal methods of knowledge and assessment, 'hybrid knowledge' is sometimes suggested as a more appropriate term for understanding practical underpinnings to sustainable land and resource management (Girard, 2015; Barbero-Sierra et al., 2017, Šūmane et al., 2018). Hybrid knowledge transcends binaries between scientific analysis and local, tacit knowledge, as it combines elements of multiple forms of knowledge acquisition (Bear, 2006). It is widely encouraged as a way of enhancing environmental understanding and adaptation, through the synthesis of different observations of local land-using communities and scientific researchers (Maynard, 2015, Raymond et al., 2010, Turvey et al., 2013). This affective, embodied quality of hybrid knowledge is also found in ecological surveyors (Lorimer, 2008), thus illustrating a complex blurring of scientific and tacit engagements with the environment.

2.3. Coproducing Environmental Knowledge for Sustainability

Understandings the characteristics of different forms of knowledge is important for conservation and related challenges. Conservation biology should be 'eclectic and multidisciplinary' (Fazey et al., 2006). Experiential knowledge of wider environmental conditions is recognised as complementary to, yet distinctive from, scientific analysis (Mukherjee et al., 2018, Sutherland et al., 2013). Studies of communities' approaches to land management note the importance of multiple knowledges and bringing together diverse perspectives (Bethel et al., 2014; Ingram, 2008; Tengo et al., 2014). Epistemological diversity is particularly common in the environmental knowledge of farmers, hunters and other land workers, and has the potential to support sustainable management practices (Lam et al., 2020, Reyes-Garcia et al., 2019). Analyses of conditions central to successful farming frequently finds individuals combining both tacit experience, and formal education and training (Barbero-Sierra et al., 2017; Šūmane et al., 2018). Farmers 'know nature through the lens of science, in various guises' (Morris, 2006, p 125), illustrating how hybrid knowledge manifests the fluidity and cross-fertilisation found between different epistemological categories of knowledge. Farmers often have significant tacit knowledge of local environmental conditions, which can support conservation initiatives on their farms (Ingram, 2008). Similarly, gaps in scientific understanding of local agricultural conditions have been successfully resolved through partnerships with local farmers, when epistemological parity of diverse knowledge systems, and knowledge-holding communities, is accepted (Šūmane et al, 2018). Oral histories of farmers' knowledge can offer a valuable perspective on land use practices, and the historical socioeconomic forces which have driven environmental changes (Riley and Harvey, 2007). Such experiential knowledge offers a rich counterbalance to scientific analyses of soil conditions and landscape development (Harvey and Riley, 2005). Efforts to develop sustainable agricultural systems benefit from constructivist approaches to working with tacit knowledge (Curry and Kirwan, 2014). Tacit knowledge can also provide critical insights on neoliberal agricultural systems which prioritise voluntary management of agrochemical hazards (Harrison, 2008). Given the centrality of industrial agriculture and contemporary environmental management practices to pollinator decline, it is helpful to consider tackling pollinator decline within the context of the hybrid knowledge systems of farmers and other land users, including those working to develop alternative land management practices. Constructive scientific and policy engagement with hybrid knowledge systems relies on a reappraisal of experts, and expertise, and the relationship of such knowledge to scientific understandings.

Fazey et al (2006) argue that experiential knowledge can complement scientific knowledge in many areas facing conservation challenges. Since environmental systems are complex, and conservation often requires immediate action, experiential knowledge is often the best evidence that is available. Within TEK and hybrid knowledge systems, recognised experts gain their community status via extensive experience which is often contextualised within an understanding of the role of broader socioeconomic conditions on ecological systems (Oteros-Rozas et al., 2013, Wehn et al., 2018). These additional insights enrich the potential for their knowledge to support conservation challenges.

2.4. Knowing Bees

While the majority of research on bee health is within the life sciences (Donkersley et al., 2020, Suryanarayanan, 2013, Suryanarayanan et al., 2018), observational data generated by beekeepers has been used alongside other forms of knowledge, and contributed to understanding the decline of heather honey in France (Lehébel-Péron et al., 2016), and the impact of neonicotinoids on bee health (Suryanarayanan and Kleinman, 2013, Maxim and van der Sluijs, 2007; 2011). Beekeepers' management practice is rooted in their observational knowledge, which generates a distinct perspective on bee health, the environment, and the seasonal cycles underpinning the bees and the flora they depend on (Phillips, 2020). This knowledge is often used in tandem with other information sources, as part of a diverse information framework that underlies their beekeeping practice (Maderson and Wynne-Jones, 2016; Phillips, 2014). It is important to note that beekeeping practices are not uniform; management practices vary and are influenced by practitioners' concepts of stewardship in relation to their colonies (Thoms et al., 2019). There has also been a rise in those who link their beekeeping to wider environmental and political perceptions (Green and

Ginn, 2014). This diversity illustrates the contextualised nature of beekeepers' application of their knowledge, and the need for a more nuanced understanding of this heterogeneous community as part of efforts to successfully maximise their potential role in arresting pollinator decline. Moving beyond a solely materialistic analysis of environmental problems forces us to engage with the wider ethical, social and epistemological dimensions which are active in the framing, and ultimate resolution, of such problems (Carolan, 2008).

Questions of how best to generate appropriate, actionable environmental knowledge resonate powerfully with considerations of beekeepers' knowledges, and their views on how to ensure bee health. Bees exist in an inherently complex world, which researchers often struggle to reduce to singular factorial analysis, understood via epidemiological methods (Suryanarayanan, 2016). Bee health exemplifies the need for a transdisciplinary analytical approach, which actively engages with multiple communities, and their diverse epistemological understandings of the challenges, and possible solutions (Suryanarayanan et al., 2018). Pollinator decline results from complex synergies (Gonzalez-Varo et al., 2013, Kairo et al., 2017). Lehébel-Péron et al., (2016) and Lezaun, (2011) find potential complementarities between scientific research and beekeepers' practical experience. Understanding – and, more importantly - resolving this crisis, requires a pluralistic analysis that engages with scientific, tacit and hybrid forms of knowledge (Phillips, 2014, Marshman et al., 2019, Donkersley et al., 2020), as well as noting the fluid nature of such knowledge forms, and how they coevolve within individuals, and knowledge-holding communities.

3. Methods

This paper sets out to explore the construction and application of beekeepers' tacit and hybrid knowledge, how they use this knowledge in their practice, and how they communicate it to others. It draws on multiple data sources, including archival materials of the UK Bee Farmers Association (BFA), material held in the International Bee Research Association (IBRA) archives, which are housed in the National Library of Wales (NLW), participant observation, and interviews with long-term beekeepers.

The Bee Farmers Association is the professional guild for a small but highly relevant sub-community within the wider UK agricultural sector; members carry out contract pollination services, and/or honey production – albeit both on a far smaller scale than that commonly found in other countries such as the US and Australia. For this project, BFA newsletters dating back to the organisations' inception in 1957 were analysed. Recurrent themes were noted and reviewed, which guided subsequent development of interview questions. Result of findings in the BFA archives guided analysis of the IBRA archives. NLW provided an Excel spreadsheet of 4,165 total items held, including1,847 items in English. This list was reviewed for key terms relating to duration and/or location of beekeeping practice, with relevant items selected for detailed study.

3.1. Archives

For the purposes of this research, of principal interest were memoirs, biographies, and autobiographies of long-term beekeepers, as well as historical records of local beekeeping associations throughout the UK. IBRA's material complemented Bee Farmers Association archival data, and data generated via interviews and participant observation. The IBRA collection held several memoirs and autobiographies of individuals who had kept bees for over forty years. The writers' descriptions of the environmental changes they had witnessed, and their beekeeping knowledge, provided detailed examples of the type and depth of environmental knowledge resultant from extensive beekeeping practice. This preliminary analysis of secondary data influenced subsequent thematic development and interview questions for this research.

3.2. Participant Observation

From 2016 to 2017, the author attended a series of local, regional, national and international beekeeping events. Often, these featured guest speakers who carry out scientific research on bee and wider pollinator health. Attending these events enabled the author to observe communication, including question and answer sessions, between beekeepers and presenters. It also facilitated meeting potential interviewees.

3.3. Interviews

After developing initial themes through analysis of archives, 39 interviews were carried out with 31 male, and 8 female long-term beekeepers. They were contacted via a collection of personal contacts, requests in beekeeping magazines, and snowballing.

The selection criteria for interviewees were their having personal practical experience of keeping bees for twenty years or more. As beekeeping in the UK has changed significantly in the past twenty years since varroa mites became endemic, it was decided that this would be an appropriate minimum length of experience to generate notable environmental observations of relevance to this project. In actuality, interviewees had an average of 40 years' beekeeping experience, and often came from families of beekeeping and/or agricultural practitioners, thus adding historical richness to their environmental insights. As the criteria for interviewees was solely based on length of practice, this allowed a wide range of styles and size of beekeeping practices to be reflected in the data, from hobbyists who kept several hives in their garden, to professionals who provided pollination services and/or produced honey on a commercial scale. While diversity of operation scale led to some commonalities amongst similar-scaled practitioners, scale and motivation for practice (hobby vs commercial) were not always the key defining features underpinning responses and knowledges.

Eleven respondents had worked as professional bee farmers, either at the time of the interview, or in the past. Others were, or had been, highly active in various beekeeping Civil Society organisations. Nearly half of interviewees reported a background in STEMM professions, which they described in interviews as relevant to their beekeeping practice. Most interviews were carried out via Skype, with a minority carried out in person. Interviews ranged from 1 to 2 h. Interviewees were advised of the purpose of the research, and gave their consent to be interviewed and recorded, with the option to withdraw at any time. All interviews were recorded, transcribed and coded in Nvivo 11 by the author. Interviews are anonymised with a code representing gender, country (England, Wales and Ireland denoted by E,W,I, respectively), a distinguishing letter, and years of practice.

4. Beekeepers Knowledges

> *Part of the psyche of people who are willing to work with insects is that they are aware of the wider environment. They are very observant, and passionate about their environment. (MED15).*

This section notes the different ways beekeepers generate, record and share environmental knowledge. Project data also notes beekeepers experiencing dissonance between their prioritisation of situated, experiential knowledge, which they recognise as central to both beekeeping and environmental understanding, and the formally generated scientific knowledge that is prioritised by other bee health stakeholders. This limits the transformative capacity of beekeepers' environmental knowledge.

4.1. Tacit, Observational Learning: The Bedrock of Beekeeping

While beekeepers frequently hold disparate, contradictory views on many subjects (Thoms et al., 2019, Scott et al., 2013, Maderson and

Wynne-Jones, 2016), empirical results from this research noted certain universal themes. One of the most notable is the central significance of beekeepers' long-term practical experience and environmental observations in constructing understanding of the complex interactions that affect their bees' health, productivity and foraging behaviour. Beekeepers practice in locations with specific climatic and environmental characteristics that demand multisensory engagement. The importance of beekeepers' highly localised, contextualised, experiential environmental observations – which some see as similar to those of other stockholders - is emphasised:

It doesn't really matter what stock you've got. Whether it's cattle or sheep or poultry or bees. …the principles (of) looking after them is the same.… People who come into beekeeping now are very much…beekeeping by numbers. In the first week in March I do this. In the third week in May I do so and so. Because that's what the book says. But the books are written by somebody who is in one particular place - and I know from getting around the country quite a bit - you could be a month apart in spring. (MEP55).

Interviewees noted how their practice generated a heightened sensitivity to wider environmental conditions, emphasising its importance in understanding what is affecting their bees, and managing their bees in response to these environmental conditions. Almost all interviewees noted how their beekeeping activities serve as a precursor to wider observations of the natural world:

I think (beekeepers) are more aware of things. And even more so now that we've had all of these problems over the years. It does make you wonder what we are building up for ourselves. Because bees are a fair indication of how…it's going to affect all pollinators isn't it? (MEG40)

Practical environmental engagement can stimulate wider questions about natural processes and relationships (Everett and Geoghegan, 2016). Consequently, this leads to a desire to understand ecological relationships, and a drive to conserve the plants and the wider environment their bees depend on.

…beekeepers have a different form and degree of botanical knowledge. They are interested in where their bees are going, and what they are feeding on, and the nectar they are bringing back. …I think once you have a certain knowledge and awareness of plants, and develop an appreciation of them, you are slightly more inclined to conserve them. (MWS20)

These interviewees exhibit characteristics of TEK as discussed in section 1a. A benefit of integrating TEK into adaptive management is the positive relationship between knowledge, and appreciation, of the physical environment in which people live, work, and engage with other species of flora and fauna (Berkes et al., 2000, Olsson et al., 2004, Oteros-Rozas et al., 2013). This knowledge is also embedded in awareness of anthropogenic impacts on these environments, and a sense of responsibility to other species. As a result of repeated observations of environmental systems, TEK users develop methods of recognising and responding to the inherently fluid, and often unpredictable shifts of resource availability in ecosystems.

Throughout project data, the significance of long-term beekeeping practice is emphasised and highly valued. Beekeepers with decades of experience frequently comment that they are 'still learning', and that 'the bees will always show you something new'.

… the beekeepers I respect the most are the ones that say "you know I've been keeping bees for 40 years and I know less now than I did when I started". That's a very honest assessment. (MEP20)

Beekeepers consistently engage with dynamic physical and anthropogenic environmental conditions; their iterative responsiveness to changing circumstances is at the heart of beekeeping. While farmers and other land-working communities are also attuned to physical environmental conditions such as changes in temperature and precipitation, the semi-wild nature of bees, coupled with the breadth, and uncontrolled nature, of their foraging range, leads beekeepers to consistently note shifting local factors affecting pollinators. Beekeepers must maintain constant awareness of, and engagement with, both climatic conditions and human actions that affect the environment where their bees forage. One interviewee expressed concern about the impact on pollinators of planned housing developments:

They are taking up all the forage land…and the trouble is when they build houses, the gardens are as big as this room. That's the difference. Whereas before, the gardens were five times that size (MEH70)

Systemic concerns, and relative powerlessness of the beekeeping community, are noted in interviewees' concern about environment challenges from farmers' actions:

(My bees are in) a long thin garden, with a long thin boundary, and the whole boundary is a long arable fields. And (the farmer) sprayed.. And I rang up the land owners straight away and complained. I said I was most unhappy. (FEH35)

A fascinating recurring theme amongst all interviewees was the development of a consciousness which 'sees like a bee'.

When I drive around the countryside now, I find myself looking at it in terms of bee habitat…I just see the whole countryside now as bee forage. It's completely changed the way I think about the seasons, too. Now, summer ends at the end of July, when most of the honey flow is over. (FWD20)

All discuss looking at nature and assessing potential sites for their bees in terms of what plants, flowers and trees they see, and whether they are good for bees. They ascribe this changed environmental perspective to their practice of beekeeping, to which they attribute an increasing awareness of their surrounding environment and ecological dynamics, particularly in terms of cumulative observations over years:

I think it is something that you can only be conscious of when you have had quite a lot of experience. …you don't really put it together until you are quite old. I find it's like that with the weather. And how it affects the flowering. It tends to be the people who have been beekeeping for a very long time who are aware of these things. (MEP45)

This sensory engagement with the physical environment creates a rich localised understanding of dynamic environmental factors (Brace and Geoghegan, 2010). Many discussed how their beekeeping practice has also generated increased knowledge of *other* pollinators, not just honey bees – and how this environmental knowledge is different from that of the general public:

I think being a beekeeper has made me much more aware of how many more bees there are - types of bees, I mean - I'm sure that to the general public, bees are bees. You know, there are big fat ones that are bumblebees, and other ones that aren't. …. And I now know much more about all the different types. (FEA40)

Considering that beekeepers are positioned as key stakeholders in pollinator protection policies, this wider knowledge around pollinators is highly valuable.

Growing environmental awareness was fundamental to developing as a beekeeper:

(Beekeeping) automatically increases your awareness (of the environment). You have to be aware if you want to progress. Yes. It's a very good educator (MIB60)

While many had expanded their interest and knowledge with formal study, all emphasised the practical element of their understanding and learning, rather than 'reading this and doing this'.

There is also an acknowledgement of the constant evolving knowledge generated by repeat exposure to different bees, colonies and environments.

I learned a lot by meeting a lot of beekeepers. …Because they have all got a different story to tell. … And I think it was worth doing the bee inspection [job], for the knowledge that you gained from doing it, it was worth it to me, it was worth its weight in gold. (MWH40)

This theme of learning by sharing and comparing experiences with other practitioners, whether from working with family members, visiting other members of a local beekeeping association, or traveling throughout an area as a bee inspector, is an important part of the development of beekeepers' knowledges.

Beekeeping is a lived experience, generating embodied environmental knowledge similar to that of farmers (Carolan, 2008) and fishers (Eden and Bear, 2011). Recording this experience, and the observations and insights resultant from analysis of practice, is another common theme throughout this data.

4.2. Record-Keeping and Construction of Knowledge

Archival and interview data present multiple references to the importance of recordkeeping and analysis as part of beekeepers' environmental knowledge construction, and resultant management of their colonies. This is relevant when considering how beekeepers' knowledges can support pollinator conservation. Efforts to understand ecological change are often challenged due to geographically and/or temporally limited data (Montgomery et al., 2020, Danielsen et al., 2005). Increased usage of records and data collected by amateur naturalists is suggested as one possible data source to support institutionalised, formal ecological understanding (Miller-Rushing et al., 2006, Primack and Miller-Rushing, 2012). Such lay knowledge is valuable to both practitioners, and other bodies involved in species monitoring and wellbeing (Eden, 2012). Observational and historical records of beekeepers, many of whom have kept bees in one area for decades, are a potentially rich data source on local environmental changes, and the factors driving them. One archival source describes the records he kept for over six decades of beekeeping, and their importance to his practice:

*'I make a note about weather, times of flowering of important nectar sources, honey yield and more, on a page opening preceding the colony entries, and at the end of the year I record the yield of each colony and the average yield per colony (winter count) in the form shown below… For me, (records) are an essential management tool.' (*Sims, 1997, p 94*)*

Another writer illustrates complex multifactorial data collection, and describes the resultant analysis from such recordkeeping:

*"1942: up to June 25, owing to poor weather, it seemed as though there would not be a honey harvest. However, at this date the weather really set in fine and at the very same time the lime trees began to bloom. During the next 18 days the hive increased in weight to 49.5 lbs. For 5 of these days (marked 'K' on the chart), when the lime trees were giving off nectar at their best, the weight went up 32.5 lbs gross, but on each of the five nights there was a loss of 2–2.5 lbs, making the increase in 5 days 22 lbs net. After this, clover nectar began to come in and the loss at night stopped. By this it appears that the lime nectar is very thin and watery as compared to clover nectar." (*Spiller, 1952, p 22–3*)*

Such data are collected and analysed in a manner that spans amateur and scientific observation. While there has been a historic preference for behaviours such as productivity and/or calm behaviour, there is an increasing drive to breed for resistance to disease, particularly varroa.

But I also try and maintain my own work in developing native bees, and varroa resistant bees. Because my bees are resistant to varroa, you see …I keep records of what lines I have got, and this is partly because I want to preserve those lines if I want to later go into DNA analysis, to sort out what I've got and what and how different they are. (MEP45)

Beekeepers' detailed recordkeeping raises important questions about the nature of this community, and their potential contribution to environmental conservation. Diverse epistemic communities utilise a range of assessment techniques in their practices, which, although carried out as hobbies, highlight the informed nature of their amateur status (Endfield and Morris, 2012). Communities of amateur naturalists and volunteers manifest a high level of expertise in their practice, which can make a significant contribution to environmental monitoring (Ellis and Waterton, 2004; 2005). However, due to the beekeeping communities' amateur status, members often struggle to have their knowledge given equal status to that of scientists; this is exemplified by two interviewees who expressed profound frustration that a published scientific paper based on their work over two decades failed to include them as co-authors, on the grounds that 'they weren't scientists'. There is also a tension between the localised knowledge generated and relied upon by beekeepers, and the broader scale of pollinator policy, which has limited capacity to reflect the highly variable conditions relevant to beekeepers.

Interviewees reported diverse levels of formality of recordkeeping and approaches to data collection and analysis. Some beekeepers admit to keeping their records and observations 'in their heads'. As one said, 'country folk don't always write things down!' While not all interviewees kept written records, they still engaged in intense, regular observations and analysis of environmental conditions and bees' responses, which underpinned their hive management decisions.

Several interviewees kept extensive records on a range of factors influencing bees and other pollinators, including flowering times, rainfall and general weather conditions. They discuss the importance of this detailed awareness of, and engagement with, wider environmental patterns and available crops and forage, as this is "what their bees survive on". Others combine their detailed observations of phenological information, with notes on bees' behaviour:

Going back a little more – 4th of March - rain all day. 11th March-cherry and plum out. The bees on hellebores. All flying well and pollen going in. Going back-February-turned very cold-hard frost all week. Snow quite heavy. Cold all week. 11°. −11 overnight. (FEH35)

Although record-keeping is highly valued and relied upon in management and assessment of environmental patterns, these records are also interpreted within an intuitive framework, resulting from practice and experience. One interviewee maintained a scale hive – these are kept constantly on a scale, and the beekeeper never removes honey from it; any variations in weight are solely the result of the colony's actions. While daily records are kept, along with local meteorological data, she talks about 'developing a feel' for the patterns in the weight changes of a scale hive. She noted that very dry, warm days are mistakenly assumed by many members of the general public to be good for bees, when actually, the lack of precipitation will result in a slower nectar flow, and poorer foraging conditions. Bees (and other pollinators) ideally need a delicate balance of precipitation and temperature, at very particular times of the year. Her 'feel' illustrates the environmental perceptions and tacit knowledge generated by beekeepers' regular environmental practice, and how these differ from observations of members of the general public. The process of record-keeping enhances and documents this knowledge, and results in a rich and distinct form of local knowledge.

4.3. Locally situated knowledge

While certain information relevant to beekeeping is broadly universal, such as the general lifecycle and biology of the colony, there are important regional variations and manifestations, eg, when particular events occur in relation to the local climate and conditions. Beekeepers' local, situated environmental understanding has been documented in Korea (Park and Yeo-Chang, 2012), France (Lehébel-Péron et al., 2016), and Japan (Uchiyama et al., 2017) with pollinators' role in local ecosystems also recognised by land workers in India (Smith et al., 2017), and Peru (Thomas et al., 2017). For centuries, beekeepers have been attuned to specific local characteristics and microclimates, and how these are relevant to the health and productivity of their bees. *One Thousand Years of Devon Beekeeping* (Brown, 1975) collates some of the oldest environmental observations associated with UK beekeeping. Its regionally specific geographical information, coupled with beekeepers' tacit engagement, provide a strong, continuous temporal context to beekeepers' local environmental observations and resultant preferences for the siting of hives based on particular observational assessments.

Local knowledge is central to recognising significant factors when choosing sites for apiary placement (Rawson, 2008). Microclimates are affected by latitude and the lie of the land: 'Narrow, steep-sided valleys produce variable air currents which sometimes make chilly gusts of wind.' (ibid, p 17). Continuous assessment over years of practice also generates heightened awareness of potentially relevant proxy behaviour of other species: 'A better guide is to notice where gnats congregate during warm summer afternoons and evenings' (ibid, p 18). Ultimately, the author advises other beekeepers that 'It is not easy to find an apiary site that meets every sensible requirement. Many are good in some ways but not so good in others, and one needs to take an overall view.' (ibid, p 25). This holistic overall understanding of the environment exemplifies a key distinguishing feature of beekeepers' knowledges.

Many interviewees and archival writers maintain multiple apiaries in areas which, to the untrained eye, may seem interchangeable. However, beekeepers' deep engagement with, and consistent analysis of multiple components results in their noting important differences between sites and responding to these differences with perpetually iterative management decisions. Local variations can include wind, frost pockets, forage differentials, altitude, exposure to incinerator waste, and more. As noted in a leading beekeeping guide (Bruyn, 1997), and in archival material (Cumming, 1945), it is clear throughout interviews that regional variations are highly significant to beekeepers.

> *Some hives are … under a heather and bracken (hill). Others are at estuary level. They get sea level and tree honey as they are in woodland area near National Trust land. They do better in a poor year, because it's warmer. The other hives do better in a sunny and hot year because they've got so much wild country, particularly blackberries, around them. But of course, they don't survive winter so well … (MWB30)*

Their high level of tacit knowledge about local environments can impact how beekeepers approach formal research on bees and the environment. Most respondents emphasised the importance of experiential local knowledge in addition to, and sometimes above, much formal scientific research, as local conditions and microclimate have such a significant impact on their individual beekeeping. Published guides on bees and beekeeping (Bruyn, 1997, Hooper, 1979, Kirk, 1994) also emphasise the importance of one's own observational learning. Beekeepers traditionally learn from mentors, colleagues, and others keeping bees in their area (Adams, 2016). Amongst the community, there is enormous value placed on the knowledge of long-term beekeepers, and a tendency for knowledge to be transmitted through social practice (Phillips, 2014). Similar intergenerational systems of knowledge acquisition and transmission are found amongst TEK holders living and working in a highly diverse range of environments, including the North American Arctic, China, and Spain (Cruikshank, 2012, Luo et al., 2009, Oteros-Rozas et al., 2013), thus illustrating how beekeepers' environmental knowledge exhibits features of TEK systems. Such locally situated knowledge can be, and is, utilised alongside more formal scientific knowledge. The result is a uniquely rich, informed hybrid environmental knowledge.

4.4. Formal Study and Hybrid Knowledge

Although interviewees highly value their experiential knowledge about the synergistic complexities and temporal fluidity of multiple environmental factors, varying types and levels of formal education and training are also used in conjunction with practical experience to inform their beekeeping practice. The result is a highly distinctive form of knowledge that transcends boundaries between amateurs and scientists, tacit and formal. It is not simply a matter of the actual data collected by beekeepers; rather, their approach is indicative of a particular mind-set and analytical approach to the natural environment in which they keep their bees.

Interviewees who came from STEMM backgrounds clearly stated that these two forms of knowledge and understanding – the observational practice of beekeeping, coupled with their technical and / or scientific training – complemented each other to generate an enriched practice and understanding of bees and the environment:

> *Because my training as an engineer – one of the things is that if things break down, you need to find the reason why. You can't just keep buying spare parts. You need to find the cause of the problem, and adjust things to suit. (MEH20)*

One interviewee was an amateur beekeeper, with a professional background in horticulture, farm management, and beekeeping. (It was not unusual for respondents to have alternated between amateur and professional beekeeping, at different stages of their lives). He also had an MSc in melissopalynology (the identification of pollen in honey). This individual combined knowledge generated from his amateur, academic, and professional experiences and training, into one integrated perspective that underpins his practice, and his engagement with the environment. He notes:

> *I think spring is very much changing. When I started in horticulture, I trained in East Malling research station here in Kent. And the blossom of the fruit trees was Chelsea flower show week. Now (that date) does not move around. It is the last full week in May. But the flowering of the fruit trees does. And it is now earlier. (MEH45)*

This respondent's linkage of observational trends, personal history, and a fixed event exemplifies benchmarking - a long-established technique used by demographers and other researchers: qualitative records are supplemented and contextualised in relation to fixed temporal data surrounding particular notable events (Axinn et al., 1999, Glasner and van der Vaart, 2009, Nelson, 2010). Many beekeepers use such dates and associated environmental occurrences as guidelines for their practice. For example, one interviewee noted 'In Ireland, you traditionally start your beekeeping on the first fine day after Saint Patrick's Day - March 17th. As well as collecting quantitative records on honey yield and weather, beekeepers use flexible occurrences to time their practice, such as recommending the first hive inspection to be carried out after currant bushes has come into flower – generally March-April. These knowledges are comfortably used alongside other, more specific, and formal sources of information.

Several interviewees came from professional scientific backgrounds and were highly engaged with current research on bees and the environment. Interestingly, while most beekeepers prioritise knowledge gained from practical beekeeping experience over what they often see as comparatively rigid, narrow analyses of scientific research, for one interviewee, even the scientific research on bees was too variable, given his background in chemistry:

> *I have found that the natural sciences are quite fascinating, coming from a pure science background. It has been an eye-opener really. I'm used to precision in science, and it doesn't quite work that way when you come onto the natural sciences! (MES45)*

The intensity of beekeepers' engagement with forage, on both an observation level, and a more scientific analytical level, was clear in both archives and interviews. This is exemplified in beekeepers' awareness of, and study of, pollen. Bee nutrition is based on collecting both pollen and nectar from flowers; the pollen is the protein source used to nourish developing brood. Beekeepers often make a visual analysis of pollen their bees have collected, based on combining knowledge of what is flowering at that time, within their bees' foraging range, with colour charts and pollen identification charts readily available (Kirk, 1994, Sawyer and Pickard, 1981). This allows most beekeepers to make an informed visual analysis of pollen collected by their bees. However, some take this interest further. Several interviewees carried out higher academic studies in melissopalynology, or studied modules offered by the British Beekeeping Association (BBKA).

I went up to a guy at Stafford who was a microscopy lecturer…. So I was able to learn a lot about how to do it. Whereas now of course you have got the microscopy exam through the BBKA. … I used to enjoy that. And then the photography through the microscope. I enjoy that as well. (MED70)

While most interviewees are not noticing significant, unexpected changes in the availability of pollen for their bees, it is the depth of their engagement with, and knowledge about pollen, and the capacity of so many of them to make detailed scientific analysis of pollen, that is noteworthy. Many interviewees displayed characteristics associated with those of professional ecologists, such as valuing nature, and having broad training in various ecological disciplines (Reiners et al., 2013). This perspective underlies their practice, and their lifelong learning throughout their practice. The analysis of pollen conforms to common understandings and methodical procedures associated with laboratory-based scientific enquiry, and subsequently generated knowledge. Those interviewees engaged in pollen analysis illustrate a high level of scientific understanding and training which exemplifies the blurring of boundaries between scientific and 'amateur' understandings (Endfield and Morris, 2012; Ellis and Waterton, 2005).

One respondent keeps his bees in an area surrounded by prime agricultural and forage plants: apple and pear orchards, field beans, and market gardens. Such sites are highly desirable amongst beekeepers, due to their quality, quantity and diversity of forage for bees. However, pollen analysis suggests that the bees tend to ignore the majority of what is easily available for them, and travel further so they can access the comparatively limited amounts of wild, unique saltmarsh plants. This interviewee exemplifies a complex, multiple, 'environmental public' (Eden and Bear, 2012). While his status as a bee researcher would be classified as 'amateur', as compared to a professional scientific researcher, this individual is a chemist by profession, who has kept bees as a hobby for 40 years. He has kept abreast of scientific research on bees and forage, has studied and analysed the pollen his bees collect, and carried out individual research projects based on his own interests and observations, as well as participating in Citizen Science projects, such as CSI Pollen (van der Steen and Brodschneider, 2015). His microscopic analysis of pollen samples is further analysed within the context of his local knowledge of plants available to his bees, within their foraging radius.

The scientifically analytical, and the tacit experiential approaches to knowledge construction complement each other in the real and complex world of beekeeping. However, interviewees often expressed unease with what they perceive as a shift in emphasis to prioritising academic study above practical experience. There is a concern that experiential knowledge of bees, where influencing factors are rarely singular, and understanding can often be difficult to quantify, is being superseded by a formal scientific knowledge of bees, which is rooted in an entomological framing of bee health (Kleinman and Suryanarayanan, 2012, Suryanarayanan and Kleinman, 2013, Suryanarayanan, 2013). This latter approach emphasises linear, singular analytical understandings, which leave little room for active engagement with real-world, highly fluid, multifactorial complexity, as observed and engaged with by beekeepers, and described extensively by Suryanarayanan and Kleinman (ibid), and also found within this research. Beekeepers' knowledges are traditionally extensive and situated within the context of a broader environmental understanding and engagement (Lehébel-Péron et al., 2016; Maderson and Wynne-Jones, 2016; Park and Youn, 2012; Uchiyama et al., 2017). While beekeepers are aware of the benefits of both methods of understanding bees and the environment, they often express frustration with a shift in emphasis which prioritises a more formal, objectivist approach to environmental understanding. This tension is exemplified by the rising status of exams and official qualifications, which is hotly debated within the beekeeping community.

It's something that crept into beekeeping in the last 20 years perhaps… if you haven't got qualifications, you don't know anything (about bees). Nobody takes any notice of you. (MEP55)

This change in emphasis is also seen in the government's bee inspection service:

When I first started in the bee inspection service, they were looking for beekeepers. Now they are looking for graduates. And they may not be particularly anything more than, you know, just beginners…(MWH40)

Such tensions are commonly found in situations where TEK is struggling to be granted parallel, or equal status, to formal knowledge (Nadasdy, 1999, Nadasdy, 2005). This is unfortunate, given the value of TEK to conservation strategies and environmental research (Barthel et al., 2013, Berkes et al., 2000, Ianni et al., 2015, Ingram, 2008). The fact that experienced beekeepers often combine their tacit experiential knowledge with professional STEMM backgrounds, as well as embarking on part time courses related to beekeeping and the environment, also illustrates the breadth of hybrid knowledge found in the beekeeping community, and its heightened capacity for constructing, and acting upon, complex ecological realities impacting pollinators.

5. Conclusion

The characteristics of beekeepers' environmental knowledge, and how it is perceived by bee health stakeholders both within and beyond the beekeeping community, is relevant to recurrent debates on the geographies of environmental knowledge and governance. This paper also speaks to practical concerns regarding how to incorporate geographical specificity and epistemological diversity within policies which are designed to be relevant to, and applied across, broad scales. Beekeepers' environmental knowledge shares many traits associated with both TEK, and hybrid knowledge systems. This knowledge has often been passed down across the generations, through practical training with family members, and other members of the beekeeping community. Their experiential learning and observation is increasingly infused with relevant scientific knowledge of bee biology, disease and more. Formal scientific study and understanding of biological processes is utilised alongside practical experience and personal observations. The result is a form of hybrid knowledge which can play a unique role in wider conservation efforts.

Beekeepers are highly informed generators and users of both formal and informal data on the environment in which their bees live. Their knowledge is highly site-specific, and responsive to local conditions, as we see in other communities where TEK is generated and applied to land management. Although beekeeping is a hobby for many practitioners, a significant level of commitment and study is often associated with their practice. The role of amateurs in studying environmental change is underestimated, although these communities frequently display a high level of knowledge. Experiential knowledge of wider climatic and environmental conditions is complementary to, yet distinctive from, scientific analysis; it also engages with wider relevant factors, such as economics, local land use patterns, and historical relationships between people and the wider environment.

Beekeepers' knowledges, and their decision-making process, are subtle, complex, and incorporate a range of information. Beekeepers' knowledges share many common features with TEK systems, which are recognised as having the potential to enhance biodiversity conservation schemes. As we strive to reverse biodiversity decline in both the agricultural and the wider environment, beekeepers' knowledges have great potential to inform these efforts, with important information on changes in phenological patterns, and the condition of local habitats for pollinators and other species, as well as the environmental impact of other land use and agricultural policies. However, due to the experiential and situated element of beekeepers' knowledges, which often lies outside of standardised methods for scientific confirmation, they are frequently dismissed by formal knowledge-holding communities. This reflects a consistent tension between localised knowledges, which generate environmental understandings and awareness of changes over time and space, and more geographically abstracted scientific knowledges which, in their efforts to reflect an objective truth, can inadvertently erase essential meanings for communities whose environmental understanding is rooted in particular locales. New forms of environmental governance, which seek to repair the damage resulting from the Anthropocene, will be more successful if they embrace locally generated and applied environmental understanding; place-based knowledges frequently incorporate both situated details of local environmental realities, as well as broader knowledges generated through scientific enquiry. More effective engagement with the situated knowledge of beekeepers can help to address the worrying decline in pollinators and other species in our agricultural systems and wider environment. Such engagement would acknowledge power differentials between the differing epistemologies of beekeepers and other stakeholders in bee health, and work to incorporate the experiential insights of this community. It would also engage with the complex breadth of beekeepers' knowledges, which contain historical and contemporary understanding of socio-economic factors relevant to pollinator, and wider conservation. While aspects of this knowledge are sometimes critical of wider anthropogenic factors affecting pollinator health and wider environmental wellbeing, it is only through a thorough and multifactorial engagement with beekeepers' knowledge that pollinator wellbeing can be improved.

CRediT authorship contribution statement

Siobhan Maderson: Conceptualization, Methodology, Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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