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RESEARCH ARTICLE

Beekeeper stewardship, colony loss, and *Varroa destructor* management

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Abstract *Varroa* (*Varroa destructor*) is a leading cause of honey bee mortality worldwide. In a U.S. national survey of beekeepers, 3519 respondents noted what they believe are the advantages and disadvantages of managing for *Varroa*, what good stewardship means in beekeeping, and whether they treated for *Varroa*. Dominant attitudes were keeping bees healthy, minimizing disturbance, and monitoring hives. We found a bifurcation in *Varroa* management beliefs. Decision tree analyses show group distinctions. *Treatment Skeptics* tend to say that stewardship means bees should not be disturbed or subjected to chemicals, and should be given forage to do their 'normal business.' This group was less likely to treat for *Varroa*. *Treatment Adherents* identify themselves as bee stewards and say stewardship means active hive management and keeping bees healthy and alive. Illuminating beekeeper stewardship is essential for a socioecological understanding of how to address challenging *Varroa* management and complex human–environmental production systems that have landscape-level effects.

Keywords Colony loss · Decision-trees · Honey bee health · Stewardship · *Varroa* management

INTRODUCTION

Little is known about beekeeper notions of stewardship, how they might vary by beekeeper type, and how personal beliefs influence management practices. As a practice, beekeeping is fraught given the onslaught of diseases, parasites, pesticides, loss of forage, and other stressors leading to high rates of loss suffered by beekeepers over the last 10 years (see Ghazoul 2005; Naug 2009; Guzmán-Novoa et al. 2010; Nordhaus 2010; Pettis and Delaplane 2010; Potts et al. 2010; vanEngelsdorp and Meixner 2010; Spivak et al. 2011; Dainat et al. 2012; Lorenz 2016; Kulhanek et al. 2017; Ryabov et al. 2017). Yet, managed honey bees play vital economic and environmental roles worldwide. In the US, the value of pollination services provided by honey bees is nearly \$15 billion (Morse and Calderone 2000). Gallai et al. (2009) estimated the total economic value of pollination worldwide, by all bees, at €153 billion (US\$216 billion). Environmentally, "honey bees support diverse assemblages of plant communities that sustain wildlife and, intangibly, add to the quality of life" (Spivak et al. 2017).

Yet, there is increasing evidence that bee populations are in decline worldwide (Spivak et al. 2011; Goulson et al. 2015). In the US, honey bee colonies declined steadily in the last century with large crashes in the 1980s, 1990s, and early 2000s (Naug 2009). However, the number of managed honey bee colonies has increased over the last decade (Steinhauer et al. 2018). One particularly daunting global challenge is that of *Varroa* (*V. destructor)* (Anderson and Trueman 2000). A study in Canada suggests that *Varroa* may be the primary factor in overwintered honey bee colony losses in northern climates (Guzmán-Novoa et al. 2010). *V. destructor* is a parasitic mite that originated on the Asian honey bee (*Apis cerana*) but transferred hosts to the European honey bee (*A. mellifera*) where it spread rapidly via colonies of bees that did not co-evolve with the parasite. *Varroa* arrived in the United States in 1987 (Le Conte et al. 2010; Rosenkranz et al. 2010), Brazil in 1972, and New Zealand in 2000 (Iwasaki et al. 2015). Australia

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remains the only major beekeeping country currently free of the mite (Iwasaki et al. 2015). High *Varroa* loads physically damage individual bees and spread diseases within colonies, thus significantly weakening them. Left untreated, *Varroa* can cause colony death.

While there is a rich literature on the biology of honey bees and beekeeping, there is limited scholarship on beekeepers' beliefs and practices. The scant published literature is recent and mostly focused on the politics of knowledge around colony collapse disorder (e.g., Suryanarayanan 2015; Suryanarayanan and Kleinman 2017). In this paper, we explore the question, How do beekeeper's stewardship concepts relate to beekeeper beliefs and practices around *Varroa* management?

THEORETICAL FRAMEWORK

The challenge of *Varroa*

Although most US beekeepers are backyard beekeepers who manage fewer than 50 colonies, most colonies are owned by a small number of commercial beekeepers who manage 500 or more colonies (vanEngelsdorp et al. 2012). No matter the size of beekeeper operations there is growing consensus that *Varroa* are, as Rosenkranz et al. (2010) note, "the greatest threat for apiculture" and managed honey bee colonies worldwide.

Varroa feed on bee tissue, which "weakens the adult bee, decreases the bee's adult lifespan, and compromises the bee's immune system" (Spivak et al. 2017, p. 4; also see Dainat et al. 2012). As *Varroa* feed on adult and immature bee tissue they often inject viruses, such as Deformed Wing Virus (DWV), into their hosts (Le Conte et al. 2010; Spivak et al. 2017). Mites suppress honey bee immunity and facilitate viral replication, increasing bee morbidity (Dainat et al. 2012). Overall, high *Varroa* levels in colonies reduce bee lifespans, depress immune systems, and increase colony mortality.

Beekeepers can only decrease the risk of bee viral infections by managing the viral vector—the population of *Varroa* in their colonies. According to Rosenkranz et al. (2010), "[w]ithout periodic treatment, most of the honey bee colonies in temperate climates would collapse within a 2–3 year period" (p. 596). Treating colonies with acaricides is not without cost. Many products and/or their metabolites, including several varroacides, are lipophilic and so readily diffuse into and accumulate in treated colonies' comb (Mullin et al. 2010), exposing bees in contaminated colonies to products their entire lives. Even short-term exposure to some common varroacides alters gene expression in bees (Boncristiani et al. 2012). Combined with increasing issues of mite populations developing resistance to some miticides (Beaurepaire et al. 2017), it is not surprising that many beekeepers and scientists alike advocate for non-chemical approaches to mite control, such as the use of mite-resistant stock (Spivak and Gilliam 1998).

Another challenge is that *Varroa* mites can develop miticide resistance, which can lead to over-application and thus high chemical pesticide concentrations in colonies and contamination of wax comb (Rinkevich et al. 2017; Spivak et al. 2017). Also, honey bees are exposed to pesticides while foraging on diverse plants that have been sprayed to control pests. The impact on bee colony health from synergistic interactions of insecticides and miticides is a serious concern; however, the use of non-synthetic mite control options, such as mechanical control methods, often has inconsistent and variable results (Rinkevich et al. 2017).

By allowing many colonies to die off to select for *Varroa*-resistant bees, some beekeepers in low colony density areas develop locally adapted bees that can tolerate *Varroa* infestations without treatment (Spivak et al. 2017). Such an approach is likely ineffective in areas that have a high-density of managed colonies, as mites can quickly spread across colonies throughout the landscape (Frey and Rosenkranz 2014). Given the complex challenges of managing for *Varroa*, there is not a single approach for beekeepers to use. In the UK, there are different perspectives among beekeepers regarding mite management (Maderson and Wynne-Jones 2016). Such differences can lead to tensions between practitioners who use less interventionist approaches and see chemical use as harmful versus those who take a more intensive management approach and may resent those who do not treat for potentially increasing regional mite loads.

Stewardship and agriculture

Some researchers argue that beekeepers are well positioned to collect and share a wealth of information on bee health given their regular contact with bees and often develop a distinct knowledge system acquired through firsthand experience (Potts et al. 2010). According to Maderson and Wynne-Jones (2016), "the irreplaceable nature of direct experience and attention to local conditions was emphasized as being fundamental to successful beekeeping" (p. 92) among beekeepers. Some note that beekeeping often leads to a change in perception of bees and the environment. Beekeepers may describe "feelings of connection and stewardship" as a result of their work with bees, feelings that can shape colony management and beekeeper practices (Maderson and Wynne-Jones 2016, p. 93).

A growing body of literature has examined the concept of stewardship across the agricultural landscape. Stewardship was most famously applied to environmental management in Aldo Leopold's (1949) formulation of the "land ethic." In agricultural production linked with environmental management, the term stewardship saw increasing use in the last decades of the twentieth century (Worrell and Appleby 2000), yet the concept was and remains ill-defined. Stewardship usually described "responsible" management but the term was used loosely, with little effort to define that responsibility. In the 1990s–2000s, stewardship generally referred to a broad land ethic of care but there are now multiple understandings of 'stewardship' (Mathevet et al. 2018).

For example, Raymond et al. (2016) found multiple stewardship conceptions and report four types of stewardship frames among certain UK farmers. The environmental stewardship frame focuses on the natural environment and the production frame focuses on producing goods. In contrast, the holistic frame is the widest conception, inclusive of environmental, economic, and cultural aspects. Finally, the instrumental frame views stewardship in terms of rules, legal definitions, and incentive programs. Different stewardship frames correlate with different practices so that a farmer's stewardship frame affects her landscape values and land management actions (Raymond et al. 2016).

Ellis (2013) takes another approach to stewardship within animal agriculture, examining what stewardship, husbandry, and dominion mean to Western US commercial beef producers. For his respondents, stewardship was about balance and was typically framed as a mutually beneficial relationship between farmer and cattle. Ellis argues that stewardship is "part of a narrative that producers use to align the actions of nonhumans with the need to produce a commodity" (2013, p. 430). Stewardship is not only about management but also about the production of self (i.e., identity as beef producer) and therefore key to understanding how agriculturalists understand themselves. In Eastern US rotational grazing dairy production, farmers defined environmental and land stewardship as their efforts to enrich pastures and manage cow behavior, as improving soil health and conservation, and as contributing to water quality (Brummel and Nelson 2014).

In their discourse analysis of direct marketing farmers, Piso et al. (2016) found eight sustainability values informing farmer practices: economic efficiency, community connectedness, stewardship, justice, ecologism, self-reliance, preservationism, and health. Respondents defined the stewardship value as how well a farmer knew her farm and could respond to disruptions. Central to this conception of stewardship is embeddedness in place, attentiveness to one's farm, and experience. Piso et al. (2016) found that stewardship was a core, constitutive goal, meaning farmers were unlikely to compromise on stewardship practices even though they might compromise on other values.

Given numerous stewardship conceptions, "carving out a discrete and well-defined identity for stewardship may be difficult" (Worrell and Appleby 2000, p. 270) yet, stewardship in general may be beneficial in "encouraging a broader view of who and what should benefit from management activity" (Worrell and Appleby 2000, p. 273). Ultimately, stewardship may operate differently at different spatial scales and use different forms of knowledge (Mathevet et al. 2018). That stewardship concepts are dynamic is important to understand farmer and other agriculturalist behavior, including that of beekeepers. Values such as those grounded in stewardship are "complexly interwoven with patterns of behavior" (Piso et al. 2016, p. 198) and impact farmer decisions and behavior (Darnhofer and Walder 2014; Garforth 2015; Piso et al. 2016). How stewardship concepts do so varies somewhat by farmer and, by extension, beekeeper type.

Research questions

In 2007, a consortium that would eventually become the Bee Informed Partnership (BIP, beeinformed.org), a collaborative bee research partnership, began an annual survey of US honey beekeepers to estimate overwintered honey bee colony losses (see vanEngelsdorp et al. 2007) and added a colony management survey beginning in 2011. BIP seeks to understand how different management practices affect honey bee health to develop and disseminate best management practices (BMPs). In 2017, a social science component was added with questions focused on identifying barriers to and facilitators of BMP diffusion and adoption among beekeepers.

Specific to this work we focused on how beekeeper stewardship concepts relate to beekeeper *Varroa* management beliefs and practices, leading to three research questions.

1. What are the range of beekeeper beliefs regarding *Varroa* management and are there discernable beekeeper types based on those beliefs? We found two types of beekeepers with diametrically opposed beliefs. Because *Varroa destructor* is such a serious problem and a focus of BIP, we found this dichotomy compelling. This observation gave rise to our other research questions.
2. What stewardship concepts are associated with the extremes in the range of *Varroa* management beliefs?
3. Is there a relationship between stewardship concepts and whether beekeepers treated for *Varroa* mites?

MATERIALS AND METHODS

Survey sample and design

The potential population of the BIP National Colony Loss and Management survey is all US beekeepers and by extension the managed honey bee population in the US. BIP uses a convenience, snowball sampling strategy, so respondents are the subset of the target population who learned about the survey and were willing to participate. BIP invited beekeepers to participate in the survey via email and the BIP mailing list (n=16 329).

The recruitment email directed participants to an online survey and asked respondents to forward the survey invitation and link to fellow beekeepers. Requests to distribute the survey were also sent to state apiculturists, industry leaders, and regional beekeeping clubs. BIP also mailed paper surveys to commercial beekeepers identified by state apiary inspectors. Past BIP National survey results were consistent with a random, stratified survey of apiculture farm operations conducted by the National Agricultural Statistical Service (Kulhanek et al. 2017), suggesting the survey captured a reasonably representative sample.

The 2017 open-ended social science questions on the BIP survey focused on beekeepers themselves, including their social networks, stewardship definitions, goals, expectations, and beliefs about *Varroa* management. BIP received 6409 responses to the 2016–2017 national survey, 95.5% identified themselves as backyard (50 or fewer colonies), 3.1% as sideline (51–500 colonies), and 1.4% as commercial beekeepers (over 500 colonies). A total of 3519 respondents answered at least one of the social science beekeeper questions and were included in our analyses while non-respondents were excluded. As noted earlier, although most beekeepers are hobbyists, most bees are managed by commercial beekeepers. Our sample is dominated by backyard beekeepers so, while it may reflect the population of beekeepers in the US, it does not reflect the population of managed honeybee colonies.

Non-respondents to the beekeeper-centered questions have significantly (p=0.005) more colonies on average ($\bar{x}$= 45) than do respondents to the beekeeper questions ($\bar{x}$=9) but a slightly smaller percentage of non-respondents are commercial beekeepers (1% vs. 1.7% for respondents). Non-respondents also report slightly higher acceptable annual colony losses ($\bar{x}$=19% vs. 18% for respondents, $p<.001$) and fewer years of experience as a beekeeper ($\bar{x}$= 7.5 vs. 9.3 for respondents, $p<0.001$). Respondents and non-respondents are similar in that over 90% of both groups earn no or very little of their annual income from beekeeping.

Concepts examined

Key concepts we tested are beliefs and stewardship. We define beliefs as convictions or ideas accepted as true. Respondent beliefs were elicited with two open-ended survey questions. "What do you *believe* are the advantages of managing for *Varroa* mites? What do you *believe* are the disadvantages of managing for *Varroa* mites?" Most responses were clearly framed as beliefs and easily coded. For example, *protecting the bees*, *give bees a chance*, and *helps the bees with one less stress factor* were all coded as a belief that "Helps Bees" is an advantage of managing for *Varroa* mites. We acknowledge that there is some imprecision and room for subjective interpretation of what qualifies as "management" and "treatment" may encompass a wide range of activities. However, the survey asks questions about specific treatment methods and products before asking about management so respondents are most likely thinking about chemical use when answering our questions.

We use stewardship as an aggregate term self-defined by respondents in response to the question, "For you, what does it mean to be a good steward of your colonies and beekeeping in general." Thus, stewardship is the respondent's own concept and in some cases includes practices. For example, 40 themes emerged for the stewardship question, e.g., "Minimize Losses" and "Keep Bees Healthy and Strong" (see Table S1). Examples of practice-based stewardship concepts include "Inspect Hive Regularly" and "Manage Disease."

Data management and analysis

We imported open-ended survey responses into NVivo version 11.4.1 qualitative software for coding. With thousands of open-ended responses, many thematic codes ("nodes" in NVivo) emerged for each question. For coding consistency, preliminary nodes were completed for a subset of respondents that three authors reviewed to clarify definitions. One author then coded all responses, periodically checking, discussing, and refining nodes with another author who reviewed a subset sample of respondents. Once coding was complete, we examined how many distinct respondents answered in a way fitting each node. We ran a Matrix Query to convert all nodes with at least 30 instances into binary variables. Exported as an Excel file, we merged these data with an existing SPSS data file of survey responses for quantitative analysis. Each respondent case in the database has either a 0 or a 1 for each node variable, where a 1 indicates the presence of the theme. We ran descriptive statistics to analyze frequencies and percentages for belief and stewardship concept responses.

We conducted several Classification And Regression Tree (CART) analyses in SPSS version 24.0 with a χ^2 automatic interaction detection (CHAID) growing method. A CART analysis creates a logic model or decision tree that indicates what variables or conditions lead to or 'predict' the state of a dependent variable. The analysis splits cases into subsets one attribute at a time. If the subset is pure, i.e., all cases are yes or no, then the tree stops. Otherwise, the analysis repeats. This leads to a series of terminal nodes that explain all cases.

We ran CART analyses for three independent variables: No Advantages, No Disadvantages, and *Varroa* Treatment (yes or no). The first two variables represent those respondents who simply wrote "none" to answer the respective questions "what do you believe are the advantages of managing for *Varroa* mites?" or "what do you believe are the disadvantages of managing for *Varroa* mites?". The treatment variable comes from the question, "Last year, did you use a treatment to try to control *Varroa* mites in your colonies?". Note there are a variety of treatments for *Varroa* to kill or otherwise eliminate mites from a colony using chemicals, oils, or organic acids.

RESULTS

Range and type of beliefs

The first inquiry focused on the range of beekeeper beliefs regarding *Varroa* management and if discernable differences emerged across beekeeper types based on those beliefs. There are a range of beliefs about the advantages and disadvantages of managing for *Varroa*, with more disadvantages named (Table 1). About 70% of respondents (n=2475) listed at least one advantage to managing for *Varroa* while 59% (n=2076) listed at least one disadvantage. To evaluate how many advantages or disadvantages respondents listed we excluded the "none" responses and summed all other variables for each question (Table 2). We then examined the relative balance of perceived advantages and disadvantages (Fig. S1) along with the "none" responses to create a *Varroa* management belief scale (Table 3).

Most respondents who answered the advantages/disadvantages questions listed only one advantage or one disadvantage in response to each question. Many other respondents listed multiple advantages or disadvantages, leaning either toward expressing more advantages or more disadvantages. Because these were open-ended responses, we cannot know how they weighted each dis/advantage. However, some of our respondents stated that there are no *advantages* to managing for *Varroa* (n=63) while others stated there are no *disadvantages* to managing for *Varroa* (n=482), representing an intriguing bifurcation in beliefs. Noting equal numbers of advantages or disadvantages, for example, does not necessarily mean ambivalence regarding treating for Varroa. However, a clear statement of "none" in response to the question is unequivocal.

We therefore focused further analysis on the two "extreme" beekeeper types that we call *Treatment Skeptics* and *Treatment Adherents*. All of the *Treatment Skeptics* are backyard beekeepers. Among *Treatment Adherents*, 95%

Table 1 Response code frequencies showing the range of beekeeper beliefs about the advantages and disadvantages of managing for *Varroa* (n=3519)

Advantages	Count	Disadvantages	Count
Keeps bees healthy	1150	Kills, weakens, or hurts bees	502
Keeps bees alive	1061	Chemicals in colony	486
Reduces disease, pests, or spreading	492	Time	420
Beekeeper management	176	Money	312
Unclear	167	Weakens bee genes	269
Reduces colony loss	163	Increases mite resistance	180
Improve production/profit	151	Is not natural selection	149
Natural or no treatment	77	Extra work for beekeeper	134
Helps neighbors	58	Unclear	133
Reduces strain	57	Additional human–bee interaction	126
Increase number of bees	40	Chemicals in honey	112
		Product or equipment issues	73
		Knowledge	60
		Chemical exposure to beekeeper	37
Total	3592	Total	2993

Open-ended questions, respondents could provide multiple responses

Table 2 Number of distinct ideas (nodes) listed by individual respondents to open-ended questions about advantages and disadvantages

Number of responses listed by a respondent	Advantages		Disadvantages	
	Frequency	Percent	Frequency	Percent
0	1044	29.7	1443	41.0
1	1875	53.3	1467	41.7
2	491	14.0	469	13.3
3	93	2.6	114	3.2
4	15	0.4	19	0.5
5	1	0.0	5	0.1
6	0	0.0	2	0.1
Total> 0	2475	70.3	2076	59.0
Total	3519	100.0	3519	100.0

are backyard, 3.7% are sideline, and 1.3% are commercial beekeepers. We conducted a binary logistic regression to ascertain the effect of beliefs about *Varroa* management on a beekeeper's likelihood to treat for *Varroa* when considering their belief that there is no advantage or no disadvantage to treating for mites. Among *Treatment Skeptics,* 92.1% reported they did not treat for mites which was 69.4 times more likely than *Treatment Adherents*, 14.3% of whom reported not treating for mites. The logistic regression model explained 38.6% of the variance (Nagelkerke R^2=0.38, $\chi^2(1)$=160.98, p<0.001) in whether a beekeeper would treat based on their status as a *Treatment Skeptic* or *Treatment Adherent*. Extreme belief about the advantages or disadvantages of *Varroa* treatment correctly predicted 86.4% of beekeepers self-reported *Varroa* treatment decisions (e.g., *Treatment Skeptics* did not treat).

Stewardship concepts and beliefs

To answer our second research question, we conducted CART analyses exploring associations between stewardship concepts and beekeeper beliefs about managing for *Varroa.* These analyses suggest a divergence in stewardship concepts between *Treatment Skeptics* and *Treatment Adherents*. The concepts of stewardship predicting those respondents who stated that there are no advantages to managing for *Varroa* (Table 4) were different than the stewardship concepts predicting those who stated the belief that there are no disadvantages to managing for *Varroa* (Table 5).

The strongest stewardship concept predictor of *Treatment Skeptics* is minimizing human–bee interaction (Table 4). These beekeepers believe, for example, that "bees know how to take care of themselves" so being a good steward of honey bees means limiting disturbance of hives. Examples of responses coded to this stewardship concept include *let bees be bees* and *let the bees be their bee-ness*. One particular response captures this stewardship concept especially well: *Don't assume to know more than the bees know. Minimize my manipulation of the colonies and let them make the best decisions.*

If a beekeeper does not mention minimizing intervention as part of stewardship, the next strongest predictor in the model is that bees should not be subjected to chemicals. These respondents wrote such things as, *no treatments*, *DON'T USE CHEMICALS in hive!*, and *no man-made chemicals*. Then, if a beekeeper does not hold this view, the final statistically significant factor in our model is the view that good stewardship means providing forage for one's bees. This stewardship concept is characterized by responses such as *supplying them with the nectar and pollen producing plants to keep them healthy and growing* and making *sure the bees I have in my hives have enough forage*.

The strongest predictor for *treatment Adherents* is the belief that stewardship is part of what it means to be a beekeeper (Table 5). For example, responses such as, *to be a bee keeper, not a bee haver*, suggest these beekeepers believed good stewardship means actively managing and/or monitoring their colonies rather than leaving them alone as if they are unmanaged feral wildlife. Another noteworthy response suggests that stewardship is central to the very purpose of life, saying, *that's why were* [sic] *on this earth to do, be good stewards*.

If a beekeeper does not mention stewardship as identity, the next strongest predictor for *Treatment Adherents* is the view that good stewardship means keeping bees healthy. In defining this stewardship concept, many respondents wrote some variation of *keeping bees healthy and strong*. Several explored this in more depth. For example, one beekeeper wrote *being a good steward of my bee colonies and beekeeping means that I will watch over my hives and do the best of my ability to keep them healthy and thriving*. Sometimes this stewardship concept was expressed as a

Table 3 *Varroa* management belief scale showing frequencies of advantages versus disadvantages categories mentioned by individual respondents along with the "none" responses (see Electronic Supplemental Materials for a more detailed description)

Scale	Frequency	Percent
No advantages (none)	63	2.8
More disadvantages than advantages	382	16.8
Equal number of advantages and disadvantages	1060	46.6
More advantages than disadvantages	288	12.7
No disadvantages (none)	482	21.2
Total	2275	100.0
Missing	1244	35.4
Total cases	3519	100.0

Table 4 CART analysis results showing which stewardship concepts predict the belief that there are no advantages to managing for *Varroa* mites (i.e., Treatment Skeptic beekeeper type). Figure S2 provides greater detail and statistics for those interested

Predictor (stewardship concept)	% Beekeeper type stating each predictor	
	Treatment skeptics (n=63)	Non-skeptics (n=3453)
Predictor 1: minimize human–bee interaction	23.8% (n=15/63)	5.8% (n=199/3453)
Predictor 2: avoid chemical use	16.7% (n=8/48)	2.4% (n=78/3254)
Predictor 3: provide forage	7.5% (n=3/40)	1.7% (n=55/3176)

Table 5 CART analysis results showing which concepts of stewardship predict the belief that there are no disadvantages to managing for *Varroa* mites (i.e., Treatment Adherent beekeeper type). Figure S3 provides greater detail for those interested

Predictor (stewardship concept)	% Beekeeper type stating each predictor	
	Treatment adherents (n=3037)	Non-adherents (n=479)
Predictor 1: stewardship identity	3.3% (n=16/479)	1.2% (n=37/3037)
Predictor 2: keep bees healthy and strong	28.1% (n=130/463)	21.1% (n=632/3000)
Predictor 3a: general hive management	6.0% (n=20/333)	3.2% (n=75/2368)
Predictor 3b: keep bees alive	4.6% (n=6/130)	10.8% (n=68/632)

duty or responsibility, such as *it is my hobby and my duty to keep the hives healthy and strong. It is also my way of giving back to fellow Americans* or *as beekeepers my wife and I are responsible for the health and well-being of our hives. We have a mutually beneficial relationship with our bees in that we do everything we can to keep them healthy and ask a minimum amount of honey in return.*

Beekeepers who hold the ‘keeping bees healthy and strong’ view of stewardship are further predicted to be *Treatment Adherents* if they also consider keeping bees alive as a central component of good stewardship. Most responses coded this way were some variation of *keep bees alive* or *help them survive*. One more respondent wrote, *the bees [are] my friends, employees and workers. I don't want them to die while in my service*.

Treatment Adherents were further differentiated by the stewardship concept of good management. This view is encapsulated in responses such as, *active management most of the year*, *to manage them appropriately*, *practicing good hive management* and in the notable (bees) *are complex superorganisms which must be well managed for their own good and that of other people's hives*.

Stewardship concepts and treatment practices

We conducted another CART analysis to answer our third research question, What concepts of stewardship predict the practice of treating for *Varroa* mites? We used treatment (yes/no) as the dependent variable and stewardship concepts as input variables. Findings of this analysis show a divergence in reported practices between *Treatment Skeptics* and *Treatment Adherents*.

The strongest stewardship concept predicting treatment relates to whether or not beekeepers see minimizing human–bee interaction as part of good stewardship (Table 6 and see previously noted response examples). Beekeepers who reported they did not treat were more likely to be among those expressing this stewardship concept. Treatment involves some disruption to colonies and beekeepers who treat may not care as much about minimizing human–bee interaction. The next strongest predictor is the view that good stewardship means avoiding chemicals, with respondents who expressed this stewardship concept more likely to report not treating for *Varroa*. The final statistically significant decision factor in this

Table 6 CART analysis results showing relationship between beekeeper stewardship concepts and self-reported treatment (yes or no) for *Varroa* mites. Figure S4 provides greater detail for those interested

Predictor (stewardship concept)	% Treatment respondent stating each predictor	
	Treated for *Varroa* (n=2512)	Did not treat (n=1003)
Predictor 1: minimize human–bee interaction	4.3% (n=107/2512)	10.7% (n=107/1003)
Predictor 2: avoid chemical use	1.6% (n=39/2405)	5.2% (n=47/896)
Predictor 3: keep bees healthy and strong	24.4% (n=578/2366)	16.7% (n=142/849)

analysis is the concept that good stewardship means keeping bees healthy and strong. More of those expressing this value treated for *Varroa* than did not treat.

DISCUSSION

Our work is one of the few studies to examine beekeeper beliefs, stewardship concepts, and practices in the US, and thus represents early groundwork on beekeepers as opposed to honey bees or beekeeping. Our findings reveal two fundamental types of beekeepers with different perspectives on *Varroa* treatments and diametrically opposed stewardship concepts. While most beekeepers believed there were advantages and disadvantages of *Varroa* treatment and host several stewardship concepts, one end of the spectrum viewed good stewardship as hands-on management while the other end saw good stewardship as hands-off. *Treatment Adherents* believed that honey bees need care and attention. *Treatment Skeptics* believed honey bees know best and should be largely left to their own devices. Thus, *Treatment Adherents* can be seen as interventionists, and likely see honey bees as more dependent on human help than do less interventionist *Treatment Skeptics*. Our results suggest that beekeeper stewardship conceptions relate to both beliefs about *Varroa* management and actual practice, supporting Raymond et al.'s (2016) finding that different stewardship frames correlate with different practices.

Ellis (2013) argues that stewardship is a narrative of co-constitution, simultaneously defining human and non-human actors in relationship and shaping agricultural producer identity. Illuminating relationships between stewardship concepts, practices, and beekeeper types may be key to understanding how beekeepers understand themselves. If stewardship is a core, constitutive goal as Piso et al. (2016) found, and values are "complexly interwoven with patterns of behavior" (p. 198) in a way that impacts agricultural producer decisions and practices (Darnhofer and Walder 2014; Garforth 2015; Piso et al. 2016), then knowing beekeeper stewardship concepts is helpful for understanding beekeeper behavior and motivations.

Early research on farmer types sought to understand the uneven adoption of new agricultural technologies (Darnhofer and Walder 2014). Through such research scholars have developed a variety of farmer typologies based on different focuses and goals. For example, one general typology is productivist versus multifunctional famers, while other typologies group farmers based on farming styles or management styles. Researchers increasingly focus on motivation to understand how different beliefs, etc. inform and shape behavior, with some studies finding farmer types based on stewardship concepts (Darnhofer and Walder 2014). Of most interest to us, and the BIP teams working with beekeepers, is the idea that understanding distinct groupings of beekeeper stewardship concepts, beliefs, and motivation can inform diverse *Varroa* mite management outreach efforts.

Garforth (2015) argues that understanding farmers' decision factors is crucial to interventions meant to prevent the spread of disease. Similarly, if beekeepers' decisions on management contribute to the spread of *Varroa* mites, then extension educators, state apiarists, and other interested parties such as BIP will want to encourage a change of practice, suggesting a need to understand beekeepers' decision factors. In their study of dairy farmers adopting multifunctional agriculture, Brummel and Nelson (2014) found that farmers emphasized multiple motivations for transitioning. This finding supports a "complex, context-specific and dynamic model of decision-making about farm management" that "challenges the notion of the farmer as motivated only by economics" common in agricultural studies (Brummel and Nelson 2014, p. 459). Garforth also notes that those who make farm decisions vary in their mix of values. "These values influence their behaviour and the choices they make" (Garforth 2015, p. 36). This has implications for those whose job it is to advise, work with, and influence agricultural producers such as beekeepers.

CONCLUSION

In his study of what factors influence farmer behavior, Garforth (2015) derived a lesson that applies equally well to interventions with beekeepers: those engaged in outreach should tailor their efforts to particular sets of farmers based on common factors, such as conceptions of stewardship. Applying this lesson to our case suggests the need to take different approaches with those beekeepers who are convinced of the efficacy of treating for *Varroa* versus those who are not. Outreach targeting *Treatment Adherents* should focus on the efficacy of particular interventions. On the other hand, outreach to *Treatment Skeptics* will need to be more fundamental to deliberate with them about intervention, and the values of hands-off stewardship. Outreach could perhaps be couched in terms of assisting honey bees in self-management, rather than as interventionist, 'hands-on' management of colonies.

Stewardship concepts can influence beekeeper practices across communities and indirectly landscape-level socioecological outcomes. *Varroa* management practices affect not only the practitioner's hives but other beekeepers' hives and pollination services in general, thus the landscape and broader food system. As a result, divergent stewardship concepts and associated practices could create or exacerbate conflicts between different types of beekeepers in an area. Currently, some beekeepers are not treating for *Varroa*, and their stewardship concepts suggest this will not change, as 'hands-off' management is a core belief. Yet, we know stewardship concepts can be influenced by peers and evolve over time (Brummel and Nelson 2014; Worrell and Appleby 2000).

As the beekeeping hobby spreads, we need community and regional deliberation about stewardship, what it means for honey bee management and the consequences for social and ecological values. Where there are higher concentrations of beekeepers, the potential for conflict, and concerns with horizontal transmission of *Varroa* (Spivak et al. 2017), stewardship concepts need to expand from individual practice to include community and landscape-level effects. Wild, native bee species are key to pollination but in decline. Honey bees play an active role in pollination beyond crop production, making them essential to ecosystem health. Gaining insight into beekeeper beliefs and practices and enriching regional deliberation about ways to approach current threats is vital to a socioecological understanding of how bees can persist in the landscape. It is a step toward stewardship of a socioecological system.

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