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Collaboration Matters: Honey Bee Health as a Transdisciplinary Model for Understanding Real-World Complexity

Sainath Suryanarayanan
University of Wisconsin-Madison

Daniel Lee Kleinman
Boston University

Claudio Gratton
University of Wisconsin-Madison

Amy Toth
Iowa State University, amytoth@iastate.edu

Christelle Guedot
University of Wisconsin-Madison

See next page for additional authors

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Keywords

complex systems, interdisciplinary science, policy/ethics, stakeholders, honey bee

Disciplines

Apiculture | Ecology and Evolutionary Biology | Research Methods in Life Sciences

Comments

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Authors

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Sainath Suryanarayanan[1,2], Daniel Lee Kleinman[3], Claudio Gratton[4], Amy Toth[5], Christelle Guedot[6], Russell Groves[7], John Piechowski[8], Brad Moore[9], Deborah Hagedorn[10], Dayton Kauth[11], Heather Swan[12], Mary Celley[13]

[1] Corresponding author; Email: ssuryanaraya@wisc.edu

[2] Assistant Scientist, Population Health Institute, Nelson Institute for Environmental Studies, University of Wisconsin-Madison, Madison, Wisconsin.

[3] Associate Provost for Graduate Affairs, Professor, Department of Sociology, Boston University, Boston, Massachusetts.

[4] Professor, Department of Entomology, University of Wisconsin-Madison, Madison, Wisconsin.

[5] Associate Professor, Department of Ecology, Evolution, and Organismal Biology and Department of Entomology, Iowa State University, Ames, Iowa.

[6] Assistant Professor and Extension Specialist, Department of Entomology, University of Wisconsin-Madison, Madison, Wisconsin.

[7] Professor and Extension Specialist, Department of Entomology, University of Wisconsin-Madison, Madison, Wisconsin.

[8] Beekeeper, Henry's Honey Farm, Redgranite, Wisconsin.

[9] Beekeeper, B's Honey, Mazomanie, Wisconsin.

[10] Farmer, Heath Farms LLC, Coloma, Wisconsin.

[11] Beekeeper, Nekoosa, Wisconsin.

[12] Lecturer, Department of English, University of Wisconsin-Madison

[13] Beekeeper, Brooklyn, Wisconsin.

Abstract

We develop a transdisciplinary deliberative model that moves beyond traditional scientific collaborations to include nonscientists in designing complexity-oriented research. We use the case of declining honey bee health as an exemplar of complex real-world problems requiring cross-disciplinary intervention. Honey bees are important pollinators of the fruits and vegetables we eat. In recent years, these insects have been dying at alarming rates. To prompt the reorientation of research toward the complex reality in which bees face multiple challenges, we came together as a group, including beekeepers, farmers, and scientists. Over a two-year period, we deliberated about how to study the problem of honey bee deaths and conducted field experiments with bee colonies. We show trust and authority to be crucial factors shaping such collaborative research, and we offer a model for structuring collaboration that brings scientists and nonscientists together *with* the key objects and places of their shared concerns *across time*.

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Introduction

Researchers increasingly recognize that developing truly effective solutions to real-world problems demands collaborative approaches that cut across the silos of traditional scientific disciplines (National Academy of Sciences 2005). Configuring research collaborations for grappling with complex phenomena requires us to consider whose voices could matter and in what ways. Using the case of declining honey bee health as an exemplar of a complex real-world problem requiring cross-disciplinary intervention, we developed a transdisciplinary deliberative model that moves beyond traditional scientific collaborations to include nonscientists in designing research. While it is not uncommon for scientists to consider perspectives offered by nonscientist stakeholders on research-related matters (e.g., Goldstein et al. 2012, North-Central Region Sustainable Agriculture Research and Education Grant Program), most scientist-nonscientist consultations are ancillary to the actual processes of experimental knowledge production (Carolan 2008). Our collaboration suggests that an iterative process of facilitated interactions between nonscientists and scientists *in conjunction with* the actual objects, sites and tools of research can enable nonscientists to offer key methodological and data-interpretive insights.

Burgeoning literatures on "the science of team science" (SciTS) and on socio-ecological systems point to the importance of boundary-spanning collaborations involving multidisciplinary teams of scientists to address complex and urgent societal problems (Börner et al. 2010, Cundill et al. 2015). Much of the SciTS work focusses on collaborations between groups of certified scientists. When nonscientists are considered at all, they are either relegated to data gathering roles or consultative capacities that tend to be removed from key everyday choices and practices related to research questions, methods, and modes of analyses (Carolan 2008). Prevalent models of re-configuring collaboration implicitly adhere to a deficit model of science literacy in which nonscientist members of the public are assumed to lack relevant knowledge (Sismondo 2010). In some cases, however, nonscientists have actively contributed to advancing understanding of real-world complex phenomena. For example, AIDS treatment activists helped advance a scientifically valid and ethical alternative to double-blind randomized clinical trials for therapeutic interventions (Epstein 1996). Indeed, in multiple instances spanning complex human diseases, livestock and crop management and environmental pollution, nonscientists have demonstrated that despite lacking scientific training or credentials, they can make valuable substantive contributions (Brown and Mikkelsen 1990, Wynne 1992, Epstein 1996). While these contributions have typically come about in the context of *ad hoc* collaborations that occurred in the midst of social controversies in which nonscientists have significant stakes, the model we offer is based on an intentionally structured process. We developed a deliberative model that fosters sustained interactions over time between nonscientists and scientists in the context of their joint participation with the actual objects and sites of research concern. Here, we report on this process.

Complexity and collaboration in the case of honey bee health

Honey bees (*Apis mellifera*) are semi-domesticated and managed social insects that are the single-most important insect species for crop pollination and honey production in the United States (US) and are a key source of livelihood for beekeepers and farmers worldwide. Despite their social and economic importance, there have been reports of elevated colony loss in recent years and declines in the number of managed colonies in some countries, including the US. A 2015-16 survey found the honey bee colony loss rate in the US was 44%, well above annual loss rates prior to 2005-06 (Kulhanek et al. 2017). Scientists agree that above-average bee deaths are caused by a combination of factors, including pathogens, pesticides (beekeeper- and farmer-applied), parasitic mites, and poor nutrition, but how these factors interact to cause the “new normal” of honey bee deaths remain unresolved, uncertain and controversial (Grozinger and Evans 2015).

The ongoing phenomenon of elevated honey bee mortality in the US and elsewhere is a complex real-world problem that cuts across the categories of “biological”, “social”, and “environmental”.

Contemporary honey bees are embedded in intertwined networks of human and nonhuman systems interacting across multiple spatial and temporal scales. Indeed, honey bees are not "wild." Over 90% of all honey bees in the US are managed by beekeepers, mainly for commercial crop pollination and honey production (Mader, Spivak and Evans 2010). Around 1,600 large-scale migratory beekeeping operations, comprising less than 10% of all beekeeping firms in the US, circulate over 72% of all colonies for pollinating various industrial farming operations in the US (Daberkow et al. 2009, Burgett et al. 2010).

Since honey bees rely on plant pollen and nectar for their nutrition, agribusinesses and farmers are also implicated in bee health. Apart from these overlapping anthropogenic networks, honey bees are also exposed to dynamic patchworks of landscapes, (agro)chemicals, and other-than-human biotic communities. Hence, questions about honey bee deaths are not narrowly biological, but are also questions about the political economies and ecologies of beekeeping and agriculture. To understand the problem, we must grapple with the full array of factors and dimensions plausibly involved.

Prevalent research practices in entomological and ecological investigations of honey bee deaths emphasize the precise isolation of the direct effects of individual factors on honey bees over relatively short time-frames (Suryanarayanan and Kleinman 2017). In this framework, to draw accurate conclusions about the causal effects of relationships between multiple interacting factors in a replicable manner and with sufficient statistical power would require a very large replicated experiment across broad temporal and spatial scales, and such an approach is practically unfeasible. This has left a crucial knowledge gap in our understanding of the ways in which multiple factors may be interacting across spatial and temporal scales to affect honey bee health (Kleinman and Suryanarayanan 2013). Practical constraints to the established experimental framework suggest the urgent need to develop alternative approaches.

To prompt the reorientation of research toward the complex reality in which honey bees (and other insect pollinators) face multiple challenges, we came together as a group, including beekeepers, farmers, university scientists with various specialties, and for part of our process-- a land manager from a federal governmental agency and a non-governmental conservation group representative joined us (Table 1). With the twin aims of facilitating genuine collaboration and fostering alternative research methods to study the complexity of honey bee decline, we undertook four structured day-long deliberations between 2014 and 2016. These deliberations were interlaced with a pair of field experiments centering on honey bees, which served as conduits for developing shared methodologies that would draw on the varieties of expertise of the participants (Figure 1).

In the initial deliberation, scientists and nonscientists drew attention to two enduring issues: the lack of diverse landscapes for foraging honey bees in heavily monocropped agricultural areas and potentially problematic management practices such as patterns of pesticide usage among farmers and beekeepers. In our second discussion, we collectively designed a honey bee field study. In the summer-to-fall period of 2014, we collected an array of field data from sixteen honey bee colonies distributed evenly across four field-sites in Central Wisconsin with relatively high and low agricultural intensities (Supplementary Materials, Figure S1). The agricultural intensity of each site was categorized with the help of collaborating beekeepers’ and farmers’ knowledge of these locales and complemented with remote-satellite data of the proportion of cropland in the 0.5-3 miles radius—the maximum range of foraging honey bees (Mader, Spivak and Evans 2010) -- surrounding each site. Given the exploratory nature of the first field experiment, we decided to gather multiple measures of honey bee health including estimates of adult population size, amounts of pupae and immature brood, levels of stored pollen and nectar, pathogen and parasite loads and pesticide residues in comb pollen across five time-points. Based on the third deliberation, in which we discussed the results of the first field study, we carried out a second field experiment in the summer of 2015, which continued the comparison between honey bee health in more and less agriculturally intensive sites, this time at eight field-sites, and with key changes in study design and measures initiated by the participating nonscientists. The purpose of the comparison was to identify ways to understand the relationships between landscape features, agricultural practices and beekeeping practices rather than looking at each one of these factors in isolation. The group met one last time in 2016 to consider the second field study results and the merits of *a place-based approach* to developing research and policy on honey bee health.

Throughout the deliberative process, beekeepers and farmers demonstrated not only their capacity to grasp complex conceptual, methodological, data and statistical issues, but also the ability to problematize and contribute to scientists' understandings and approaches. For example, nonscientists drew upon their practical knowledge of cranberry pollination to explain sources of variability that were construed as "noise" by one of the scientists, who showed a graph depicting a linear statistical relationship between cranberry yield and number of honey bee colonies per acre. Beekeepers and growers pointed out agronomic characteristics of particular cranberry marshes such as the surrounding habitat and cranberry variety, as well as the proximity of honey bee colonies placed on neighboring cranberry marshes, as sources of variability in the relationship between number of honey bee colonies and cranberry yield.

However, in the first two deliberations, there was little substantive contribution from nonscientists due, we believe, to a lack of trust and authority differentials between the different stakeholder groups represented by the participants. Beekeepers and farmers, for example, were skeptical of each others' patterns of pesticide use and the veracity of claims regarding harmful effects on honey bee health. Similarly, small-scale stationary beekeepers blamed migratory crop-pollinating beekeepers of becoming vectors of honey bee pathogens, while the latter criticized the former for not effectively managing for parasitic mites and allowing their colonies to become carriers facilitating the spread of mites. In the initial discussions around the appropriate design of the first field experiment, beekeepers and farmers largely deferred to the scientists, who promoted a traditional approach, where the effects of each factor could be examined in isolation and compared to the effects of each combination.

These social dynamics shifted in subtle yet significant ways after the first field study. In contrast to the deliberations before the first field study, it was the nonscientists who initiated key methodological innovations during the third deliberation, where we discussed the design of the second field study. The results of the first field experiment (Supplementary Materials)— the most striking of which was that only two out of eight colonies survived in the highly agriculturally intensive sites compared to five out of eight colonies in the less agriculturally intensive sites (Supplementary Materials, Table S1)-- led the nonscientists, especially beekeepers, to express significant concern about the methods of data collection in the first field experiment. The scientists had pushed for more rigorous and extensive data sampling, which in practice, meant that each colony was open for at least 25 minutes. For the beekeepers, this was inordinately long and overly invasive, with potentially negative ramifications for colony health. In deploying these critiques and in suggesting rapid, less-invasive data collection methods of gauging colony health, beekeepers drew on alternative modes of observation and measurement. These included attention to smell and sound (e.g. a high-pitched noise emanating from the colony suggesting that it is queen-less) and visual measures (e.g. a colony's "brood pattern"). Utilizing such beekeeper modes of observation, one of the beekeepers noted that colonies he was managing commercially (but not for experimental purposes), which were at the same four field sites of the first field study, performed much better than the experimental ones. Based on this, the nonscientists proposed a key shift in the experimental design for the second field experiment-- to have a pair of colonies at each site, one that would be exposed to intensive commercial beekeeping management and the other not. The results of the second field experiment (Supplementary Materials, Figure S6), while not meeting the widely used statistical *p*-value threshold of 0.05, suggested a trend: more intensive beekeeping management practices seemed to make a bigger impact on parasite and pathogen loads in places with higher intensity of agriculture than in places with lower intensity agriculture. Nonscientists also initiated discussions during the deliberation that drew on their deep knowledge of local features of the places where colonies were located to explain sources of variability in the data.

The study's breakthrough in the quality of participation by nonscientists was the result of shifts in the tenuous dynamics of authority and trust between the participants, which we believe were enabled by the participants' sustained interactions over time with each other and with the honey bee colonies in the field experiments. Meetings were structured *longitudinally* over a span of two years and facilitated in ways that sought to encourage input from nonscientists. For example, some of the deliberations were held in a beekeeping operation and in a farming operation, enabling participating scientists to better appreciate nonscientists' varieties of knowledge, practices, and constraints. Beyond the day-long meetings, the honey bee field experiments required participants to interact over time not only with each other in the processes of design, implementation and analysis, but also with honey bee colonies and field-sites.

The process was iterative, allowing for adjustments to be made based on the overlapping practical experiences of both scientists and nonscientists, with time to build relationships and trust. Participating *over time* in the field experiments allowed the nonscientists, especially beekeepers, to experience the choices, challenges and practices of experimental research and provided them with opportunities to share their own experientially-based knowledge and data-related insights about honey bee colonies. The field experiments intertwined with the day-long meetings thus sensitized the nonscientists and scientists to each others' understandings, enabling them to relate to the research meaningfully and gave the nonscientists a shared sense of creative ownership of the research.

A New Model

Our venture to enhance collaborations between scientists, beekeepers and farmers offers a model for future field experiments in honey bee research that could arguably allow for better understandings of the complex biotic, abiotic and societal matrices shaping the health and decline of honey bees. In contrast to the originally conceptualized experiment, in such field experiments, what counts as signs of health and disease and how to count these would be assessed jointly through integrated approaches, observations, and interpretations of participating beekeepers, farmers and scientists. While experimental designs would be structured to eliminate artifactual results, they would not narrowly adhere to arbitrary thresholds such as the statistical *p*-value of 0.05, which constrains efforts to capture subtle yet plausibly important interactive effects, and which is congruent with the emerging recognition of the widespread over-reliance on *p*-values in experimental biology (Wasserstein and Lazar 2016).

Beyond honey bee health, the ultimate breakthrough of our study lies in its offering a mechanism for enhancing the social dynamics of trust and authority across scientist-nonscientist boundaries in contexts of making knowledge that are marked by high levels of uncertainty, complexity and public concern. Historically established dynamics of trust and authority between various nonscientist stakeholders and scientists do not change overnight, and the breakthrough we achieved required careful attention to the spatio-temporal structure and process of collaboration. Dynamics of trust, power and authority are absolutely crucial in shaping the success or failure of any knowledge production enterprise.

While our initiative did not generate novel or actionable substantive biological findings, by demonstrating the social conditions necessary for carrying out genuinely collaborative research between scientists and nonscientists, our study offers a template (Figure 1) for teams of scientists and nonscientist stakeholders to co-organize transdisciplinary experiments that might potentially lead to new insights into complex real-world problems. In our study of scientist-nonscientist collaboration in the case of honey bee health, participating scientists realized that they could not have gotten to the second field experiment without learning from beekeepers and farmers about how the latter see their particular situations. Participating nonscientists, on the other hand, increasingly felt like they had something valuable to offer in terms of methodology and data analysis.

Our study demonstrates that nonscientists who stand to be primarily affected by the research can offer valuable methodological and other insights in investigations of complex real-world phenomena. Their involvement can complement and change the research questions, methods and interpretive frames used by scientists to answer them. Furthermore, our deliberative “experiment” provides a process-based model for enabling substantive contributions by nonscientists to knowledge-making along real-world and complexity-oriented lines (Figure 2).

Conclusion

An increasing number of governmental funding agencies and research institutions are recognizing the value of re-organizing collaborative research in ways that transcend disciplinary silos and individual-investigator-oriented reward structures (e.g., see National Institutes of Health Funding Opportunity). Our study suggests the value of extending collaboration beyond scientists, at least in cases where primarily affected nonscientists possess expertise to contribute to understandings of complex real-world phenomena. Importantly, our proposal is not relegated to scientists consulting with nonscientist stakeholders. Rather, our model proposes structuring collaboration *across time* in a way that brings scientists and nonscientists together *with* the key objects and places of their shared concerns, thus setting the stage for creating new complexity-oriented knowledge.

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Sainath Suryanarayanan (ssuryanaraya@wisc.edu) is affiliated with the Population Health Institute and the Nelson Institute for Environmental Studies in the University of Wisconsin-Madison. Daniel Lee Kleinman is with the Department of Sociology in Boston University. Claudio Gratton, Russ Groves and Christelle Guedot are in the Department of Entomology in the University of Wisconsin-Madison. Amy Toth is in the Department of Ecology, Evolution, and Organismal Biology and the Department of Entomology at Iowa State University in Ames, Iowa. John Piechowski is with Henry’s Honey Farm in Redgranite, Wisconsin. Brad Moore is with B’s Honey in Mazomanie, Wisconsin. Debbie Hagedorn works with Heath Farms in Coloma, Wisconsin. Dayton Kauth and Mary Celley are beekeepers. Heather Swan is in the Department of English at the University of Wisconsin-Madison.

Table and Figure Captions

Table 1. Stakeholders enrolled in the study. Numbers in brackets denote the number of individual participants representing the stakeholder group.

Figure 1. Timeline and stages of the process for structuring transdisciplinary collaboration. The graphical summary and timeline of the process undertaken to build transdisciplinary collaboration including goals and/or accomplishments in each stage of the process. Four structured day-long deliberations involving various scientific and nonscientific stakeholders were carried out between 2014 and 2016. These deliberations were interlaced with a pair of field experiments centering on honey bees in 2014 and 2015.

Figure 2. Transdisciplinary deliberative model for collaborative research on complex phenomena. This process-based model for enabling substantive contributions by nonscientists entails not only sustained interactions over time between scientists and nonscientists, but also shared interactions with the actual research objects of concern.

Figure S1. Relative agricultural intensity of field sites in Central Wisconsin. The agricultural intensity of each site was determined based on participating beekeepers' local knowledge of the area and was verified by computing the surrounding acreage of corn, soy, and potato crops within 0.5 miles, 1.5 miles and 3 miles of the field sites based on pixel data extracted from the National Agricultural Statistics Service's CropScape (https://nassgeodata.gmu.edu/CropScape/).

Distances between sites were at least 6-7 miles, diminishing the likelihood that honey bees from one location interacted with one another. Sites Decker, Sheriff (2014 and 2015), Marion and Schmidt (2015 only) were categorized as lower agricultural intensity; sites Hancock, Heath (2014 and 2015), Flyte and Stratton (2015 only) were categorized as higher agricultural intensity.

Table S1. Colony survival (2014). Colonies were counted as dead if they contained no eggs and no brood, including pupae. Sampling occurred in October 2014. 70% ethanol was accidentally spilled over central comb frames in the top hive-box of one colony in the Decker site during September sampling.

Figure S2. Amounts of adults and immature bees in colonies from 2014 field sites. (A) The surface area of comb occupied by uncapped brood estimated the amount of immature larvae and eggs. (B) The surface area of comb occupied by capped brood estimated the amount of pupae. (C) Adult population of each colony was estimated by the number of frames covered by adult bees. A 32-square metal grid was placed along the face of each comb frame to estimate the number of squares containing various stages of brood.

Figure S3. Nutrient stores in 2014 colonies. (A) Amount of stored nectar. (B) Amount of stored pollen. A 32-square metal grid was placed along the face of each comb frame to estimate the number of squares containing pollen and nectar.

Figure S4. Parasite and pathogen levels in 2014 colonies. (A) *Varroa* loads. (B) *Nosema* levels. We collected approximately 200 honey bees in ethanol from the central comb-frames of each colony, which we then processed in lab for mite and *Nosema* levels using standard protocols (*The COLOSS BeeBook Part I*: https://www.tandfonline.com/toc/tjar20/52/1).

Figure S5. Pesticides in comb pollen of 2014 colonies. (A) Pesticide load. (B) Frequency of pesticide detections. We removed approximately 10 cm x 12 cm sections of comb containing wax and pollen from each beehive, which we stored at -80 degrees Celsius. 16 pollen samples were sent to the US Department of Agriculture's National Science Laboratories (Gastonia, North Carolina) for an Apiculture Comprehensive Pesticide Screen.

Figure S6. Inter-colony variability in mites, *Nosema*, and adult bees in 2015. (A) Mite levels. (B) *Nosema* spores. (C) Adult population size. Variability in mites and *Nosema* were more pronounced in the intensively cultivated sites than in the locations of lower agricultural intensity. In the locations of lower agricultural intensity, mite and *Nosema* levels were similar for colonies receiving differential beekeeping management and comparable to mite levels in the more managed colonies of intensively cultivated sites. Colonies undergoing relatively less beekeeping management had higher population sizes than more intensively managed colonies across all sites, and this difference was retained within each landscape type as well.