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Policy analysis

# Towards a U.S. national program for monitoring native bees

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ABSTRACT

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North America has more than 4000 bee species, yet we have little information on the health, distribution, and population trends of most of these species. In the United States, what information is available is distributed across multiple institutions, and efforts to track bee populations are largely uncoordinated on a national scale. An overarching framework for monitoring U.S. native bees could provide a system that is responsive to national needs, resources, and capacities. Five major action areas and priorities for structuring a coordinated effort include: (1) Defining the scope, aims, and cost of a national native bee monitoring program; (2) Improving the national capacity in bee taxonomy and systematics; (3) Gathering and cataloging data that are standardized, accessible, and sustainable; (4) Identifying survey methods and prioritizing taxa to monitor; and (5) Prioritizing geographic areas to be monitored. Here, we detail the needs, challenges, and opportunities associated with developing a multi-layered U.S. national plan for native bee monitoring.

## 1. Introduction

Bees are a highly diverse and functionally important group of pollinators for many flowering plants (Ollerton et al., 2011), including some of the world's most nutritious and economically valuable agricultural crops (Eilers et al., 2011). Collectively, animal-mediated pollination services for food crops are estimated to comprise an annual global market value of $235–$577 billion (IPBES, 2016). Managed bee species play important roles in contributing to crop pollination services, especially the western honey bee (*Apis mellifera*) and some species of mason bees (*Osmia*), leafcutter bees (*Megachile*), and bumble bees (*Bombus*). However, diverse wild pollinators also contribute substantially to global pollination needs in managed ecosystems, often more than managed bees (Breeze et al., 2011; Garibaldi et al., 2013; Grab et al., 2019). In addition to their agricultural significance, native bees also play critical roles for native plant pollination, including for rare and threatened plant species (Geer et al., 1995; Kwak et al., 1996; Tepedino et al., 1997; Larson et al., 2014; Tepedino et al., 2014; Fowler, 2016; Youngsteadt et al., 2018). Native bees also represent a significant proportion of natural biodiversity in the United States, with corresponding intrinsic value (Kleijn et al., 2015; Senapathi et al., 2015). Globally there are more than 20,000 bee species, and at least one fifth of this global diversity ($>$ 4000 species) is native to North America (Michener, 2007; Ascher and Pickering, 2011).

Several recent studies have documented widespread insect declines (Hallmann et al., 2017; Seibold et al., 2019; van Klink et al., 2020), including for bees and other pollinators (Biesmeijer et al., 2006; Potts et al., 2010; Powney et al., 2019). The U.S. Government has recognized the importance of pollinators and a national need to protect them (Executive Order No. 13514, 2009; Vilsak and McCarthy, 2015). At the Federal level, a variety of programs through the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) and Animal and Plant Health Inspection Service (APHIS) track the status and health of the managed, non-native western honey bee. However, no national program exists in the United States for monitoring native bees. Without such a monitoring program, historical baseline data on populations at ecosystem-wide and biologically relevant scales (spanning state and regional boundaries) are not available. This limitation makes it difficult to assess population trends and identify bee communities that require conservation action (Inouye et al., 2017), and additionally, to identify and protect those wild bee species that contribute most to ecosystem function and agricultural productivity.

Thus far in the United States, efforts to quantify changes in the status of native bees have typically been either locally focused (e.g., at the level of states or smaller regions), or limited in taxonomic scope (Grixti et al., 2009; Cameron et al., 2011; Bartomeus et al., 2013; Burkle et al., 2013; Strange and Tripodi, 2019; but see Colla et al., 2012). A national monitoring strategy would provide a means for systematically detecting population-, species-, and community-level status and trends across the country with comprehensive and coordinated data sets necessary for rigorous statistical analyses. Documenting these trends in native bees is essential for identifying and evaluating the efficacy of programs designed to maintain their populations and improve bee health.

A comprehensive national native bee monitoring plan would effectively include methods to measure interspecific differences in life history, habitat preferences, foraging ranges, and host-plant preferences, as well as the high inherent variability in bee populations across space and time (Williams et al., 2001), while remaining scientifically rigorous and biologically informative. One way to achieve these goals is to develop a coordinated effort among many scientists, policy makers, and other stakeholders.

## 2. Management of an overarching national monitoring framework

Coordination, funding, management, and implementation of a national monitoring effort could range from being centrally directed by a single organization to a dispersed network of multiple partners. On one end of the continuum is an entirely federally-directed and implemented program, and on the other a non-directed, dispersed network. Central to any effort will be the adoption of a core set of survey techniques and data standards, determined a priori, leading to standardized data stored in a unified public data repository.

A centrally managed, federally directed program would assure consistent and uniform data, but it would be expensive and logistically demanding. Examples of federally funded monitoring programs in the United States are the current North American Breeding Bird Survey and the previous (1997–2015) North American Amphibian Monitoring Program. A non-directed, dispersed network would require methodological consistency and clear communication among disaggregated monitoring efforts, which may have unique core priorities and objectives. A dispersed network could be effective as a national strategy if participating research groups collected and stored data in a consistent and accessible way. An example of a successful, more-dispersed network is the Nutrient Network (nutnet.org), a global, open-source ecological data collection network (Stokstad, 2011). Although a core set of survey techniques, taxonomic practices, and data standards would be fundamental to the success of a dispersed network, it would also allow researchers to incorporate additional research components. Even a dispersed network would require some coordination to ensure that data collection is appropriately distributed geographically and spatially, and to maintain transparency about the goals and outcomes of monitoring projects. An advantage of this dispersed network is that it would not require as much novel infrastructure development as compared to a de novo, centrally-managed federally-directed program, because many native bee monitoring programs – although disparate and without overarching coordination – are already underway. The primary need in establishing a dispersed network would instead be in developing effective communication and coordination among network partners.

Given the costs and benefits on either end of this continuum, it is apparent that an overarching strength of this conceptual framework is flexibility. A national monitoring program need not be static along this continuum of directed coordination. With proper stewardship, it could evolve over time in response to future national needs and availability of resources and capacities.

## 3. Needs, challenges, and opportunities

Five major action areas are important for structuring a U.S. national native bee monitoring effort: (1) defining the scope, aims, and cost of a national effort; (2) improving and better supporting the national capacity in bee taxonomy and systematics; (3) gathering and cataloging current and future data to assure accessibility and sustainability; (4) identifying optimal survey methods and priority taxa; and (5) identifying priority areas for monitoring.

### 3.1. Defining the scope, aims, and cost of a national monitoring effort

Successful adoption and implementation of a national native bee monitoring effort requires clear articulation of its benefits, costs, and specific aims. We argue that to achieve widespread buy-in from scientists and the public, a national monitoring framework must have two essential elements beyond the operational details of its component strategies. First, there should be an assessment of the tractability of different sampling strategies and the levels of biological inference that each allows (Carvell et al., 2017; O'Connor et al., 2019). Assessments of both the effort required and information value of different strategies could be achieved through expert consensus-building. Second, the broad array of tangible gains should be assessed by diverse stakeholder groups whose members would benefit from a national scale effort. For example, one goal of monitoring is the early detection of species declines, to facilitate rapid responses to mitigate local extirpation or species loss. In agricultural systems that are heavily dependent on wild pollinators for crop pollination, if declines in dominant pollinator species are detected, quick interventions might be essential for ensuring continued profitable yields.

Robust assessments of costs and benefits will be necessary to generate compelling arguments for widespread buy-in for a national monitoring effort. For guidance on balancing the aims of scientists and stakeholders, we can look to existing large-scale monitoring efforts. For example, the UK Pollinator Monitoring Scheme in Great Britain is supported by a combination of funding from governmental and nongovernmental sources, and underwent a period of development and testing prior to implementation to identify the most effective practices to meet the greatest number of stakeholder needs (Carvell et al., 2017). A recent study that evaluated the costs and benefits of native bee monitoring in the UK determined that the cost of monitoring is vastly lower than the value of crop pollination services (e.g., monitoring costs <0.02% of the crop production value predicted to be lost with a 30% decline in pollinator populations), and additional savings can be generated from monitoring designs that minimize research costs (Breeze et al., 2020).

### 3.2. Improving and better supporting the national capacity in bee taxonomy and systematics

Most sampling strategies for bees involve specimen collection (i.e., the collection and preservation of whole bees). This activity generates enormous numbers of specimens, and associated data, that need to be processed, identified, and curated in physical and digital repositories. Collecting specimens is important for ensuring reproducible research, especially for small-bodied animals that can be difficult to identify on the wing (Turney et al., 2015). Completing identifications and making data accessible in a timely manner are additionally important for time-sensitive conservation actions. At a national scale, collecting and curating specimens as a central part of bee monitoring is complicated by the high taxonomic diversity of native bees in North America. Unfortunately, there is a paucity of researchers with the advanced taxonomic training needed for accurate species identification. Furthermore, a significant proportion of the world's bee fauna likely remains undescribed (Michener, 2007).

Together, these impediments pose a taxonomic 'bottleneck' that often results in long wait times to get specimens identified. This bottleneck could be overcome by creating more job opportunities for bee taxonomists, increasing formal training opportunities in bee taxonomy, continuing support for or augmenting existing training opportunities (e.g., the American Museum of Natural History's Bee Course; thebeecourse.org), and developing new taxonomic tools to make species identification easier and more cost effective, such as morphometric and molecular (Creedy et al., 2020; Darby et al., 2020) approaches to species identification.

The U.S. is home to some of the world's most comprehensive entomological collections (Nishida, 2009), with >220 arthropod collections housing an estimated >267 million specimens (Cobb et al., 2019). With improved financial support and coordination, these institutions would have the capacity, expertise, and infrastructure to both continue and expand their work in addressing taxonomic impediments. A digital and open access national reference collection for native bee identification would provide a valuable resource for the research and monitoring community. Such a resource would also be beneficial for engaging non-experts, such as community scientists (Kremen et al., 2011) and school groups, in aspects of a national monitoring program. A digital collection could be developed de novo or could be modeled after other effective resources, such as AntWeb (antweb.org) and Discover Life (discoverlife.org).

### 3.3. Gathering and cataloging data for accessibility and sustainability

A successful long-term national monitoring program will generate broadly accessible, continuous, and reliable authoritative data sets that span multiple time periods, sites, and species, and can be used to explore and answer a broad range of questions. Developing repositories for these data will require a transparent and systematic digital infrastructure, along with robust national standards for data management and mandatory minimum data fields. Ideally, these data would also be compatible with other national and international pollinator monitoring efforts, such as the Pan-European Assessment, Monitoring, and Mitigation of Stressors on the Health of Bees (POSHBEE – https://poshbee.eu) program; the All-Ireland Pollinator Plan (https://pollinators.ie); and the UK Pollinator Monitoring Scheme (https://www.ceh.ac.uk/pollinator-monitoring). This would ultimately allow data to be analyzed at larger, international scales, which is important for assessing pollinator groups that span international boundaries. Each physical bee specimen should be linked to a unique digital record, with associated information such as the species identification method, taxonomy (scientific name, taxonomic code, higher taxonomy), locality, date, collection and storage information, and any additional, related information, such as molecular data. New data fields could be added as the national effort develops. Existing national resources can offer guidance; the Darwin Core data standards (Wieczorek et al., 2012) and the United States Geological Survey's Biodiversity Information Serving Our Nation (BISON – https://bison.usgs.gov) application provide species occurrence data, and iDigBio.org provides vouchered specimen data (Page et al., 2015).

### 3.4. Identifying survey methods and priority taxa

To assess the magnitude and intensity of changes at the population, species, and community levels, survey methods need to be standardized among collection efforts, and also balanced with consideration for minimizing impacts monitoring could have on populations. Studies have estimated both the sampling effort needed to accomplish these goals and the potential impact of destructive sampling (LeBuhn et al., 2013; Gezon et al., 2015), and also the relative efficacy of various commonly-used methods, such as pan trapping (Portman et al., 2020). Monitoring is further complicated by the high mobility of adult bees, their often short periods of flight, and the high inter- and intra-annual variation in adult bee presence. Furthermore, to ensure that over-collecting is minimized, especially for species with limited or declining populations, it will be important to build periodic assessments of demographics into any methodology.

To account for these issues, a national monitoring program might take a targeted approach and focus on priority bee taxa, host plants, or habitats. For example, a focus on bees visiting a single plant group with a large geographic distribution (especially those that host large numbers of specialist and generalist bee species) could help narrow the range of focal taxa, while providing adequate data for identifying overall trends and variation among sites and geographic regions. Surveys targeting threatened bee populations could also be employed (Graves et al., 2020), especially when historical data exist for the species (Burkle et al., 2013). However, if sampling is expected to impact populations substantially (as in the case of rare and endangered species), alternative monitoring techniques must be employed that do not require destructive sampling, such as photographs or visual inspections. This strategy is not ideal, in that some types of data are lost when there is no physical specimen; however, improved visualization for advanced morphometric analyses and other analytical approaches such as population, range, and environmental modeling can mitigate certain drawbacks (Minteer et al., 2014). As described above, the design aspects of a national program will likely be driven by a balance between scientific interests and the needs of the funding bodies that support such a program.

A U.S. nationwide monitoring plan could, in addition to providing an important baseline, establish a framework for collecting and accessing data to move us beyond simple relative abundance information towards evaluating, both observationally and experimentally, ecological and anthropogenic drivers of bee declines. This goal requires environmental data, which may include abiotic conditions at monitoring sites, or biological data on bee diseases, parasites, or nutrient levels at monitoring sites. In addition, it would be beneficial to have data that characterize plant resources, habitat, and other landscape or environmental factors associated with each site that is monitored. The nature and prioritization of these additional ecological data and any associated protocols, experimental or otherwise, may vary among collection localities depending on the specific needs of a given study area and available resources. Rapidly-advancing technologies such as remote sensing (Turner et al., 2003), and the leveraging of existing infrastructure for ecological or landscape data, might hold particular promise for collecting or accessing large-scale ecological data sets for contextualizing data generated from a national monitoring program.

### 3.5. *Prioritizing geographic areas*

Not all locations in the United States need to be monitored to identify declining bee taxa, nor could they be under any realistic funding scenario. If the strategy were to develop into a more centralized program, it would be necessary to prioritize monitoring sites by geographic areas based on a set of decision criteria. These prioritization criteria would require buy-in by a wide variety of stakeholders who may have unique goals and opinions, and may vary across monitoring locations. Priority considerations might include the following:

1. Areas with a high concentration of pollinator-dependent agricultural crops.
2. Areas of high conservation concern, for example, ecosystems that harbor rare and endemic bee and plant species (e.g., dunes, longleaf pine savanna).
3. Areas with rapidly changing habitat due to land use or climate change, or where bee communities are known to be changing.
4. Areas of high bee biodiversity, such as southwestern deserts (Arizona, New Mexico, southern California).
5. Areas where extensive data relevant to bees already exist, for example sites associated with the National Ecological Observatory Network (NEON – neonscience.org).
6. Under-sampled areas where a paucity of bee sampling has been identified through data gap analyses.
7. Areas where high quality data sets from bee collections already exist to provide a historical baseline for interpreting contemporaneous data.

To prioritize locations for monitoring projects, statistical analyses should be used to model the sampling effort needed to extract useful information from a given area. Such spatially explicit modeling might reveal locations where patterns could be extrapolated from one geographic area to the next. Incorporating climatic events, different landscape management strategies, habitat suitability, and other predictive factors into these models could help identify priority areas for monitoring native bee populations (Koh et al., 2016). Modeling could also be used for risk analyses to identify locations and taxa under higher risk of extinction, greater exposure to stressors (e.g., contaminants), or other threats.

## 4. Opportunities and capacity building

A U.S. national native bee monitoring program, as described here, would generate a comprehensive data set that could serve as a baseline for assessing trends and factors associated with both increases and decreases in bee abundance and diversity. The monitoring program would involve multiple layers, from targeted public-private partnerships to complex bee community ecology studies. A network of monitoring sites and programs that engages people from multiple sectors of society, including federal and local governments, community scientists, crop producers, universities, cooperative extension, private industry, and conservation organizations, will help create a strong network. We anticipate that, at its inception, a national monitoring framework might be a loose network of participants, but as the network and monitoring framework grow in scope and scale, a more centralized program could be established. Recent efforts to discover the scope and methods used in native bee survey and monitoring, such as a USDA sponsored meeting of bee scientists in Sheppardstown, WV (in 2018), underscored the diversity of techniques and philosophies currently used in monitoring efforts. As a result of that meeting it is recognized that, ideally, the United States will undergo a period of strategic plan development for native bee monitoring, as has occurred in places like the UK (Carvell et al., 2017). This will allow researchers working within the United States to identify the particular monitoring program details that are most effective for this country. This is the aim of a recently-initiated USDA-funded National Native Bee Monitoring Research Coordination Network (RCN). Curating and maintaining data generated from the effort will be paramount, regardless of the structure and complexity of the national effort.

Many of the challenges outlined here are not specific to monitoring native bees. For example, the initiation of the USA National Phenology Network (https://usanpn.org) required meeting similar challenges for identifying species to monitor, recruiting participants, and creating a robust data management system. Methodologies and infrastructures developed towards a national bee monitoring effort could have far reaching impact and vice versa. For example, bottlenecks imposed by a lack of taxonomic expertise and resources exist for many taxa (Schindel and Cook, 2018); ongoing research efforts to overcome these barriers in other systems could inform the scope and scale of native bee monitoring, and any taxonomic methodologies developed for bees could also have broader utility. Additionally, although we have focused our perspective on monitoring native bees due to their preeminence as pollinators, a more comprehensive monitoring scheme might also track other pollinator groups, and also changes in pollination through time (Hegland et al., 2010). Efforts to monitor native bees might also lead to infrastructure for tracking populations of non-pollinating insects.

Data generated by a national native bee monitoring program will provide a means to measure and evaluate trends and population dynamics, and to assess the efficacy of bee management and conservation programs at multiple scales. Only with this ability to evaluate management and conservation efforts can we assure their success—a success on which the bees, the plants they pollinate, the ecosystems and crops they support, and ultimately we, are dependent.

## CRediT authorship contribution statement

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## Declaration of competing interest

The authors declare no competing interests.

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