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A call for standardization in wild bee data collection and curation

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Abstract. Standardizing data collection methods is essential for advancing research, monitoring, and conservation efforts on bees. Greater consistency in data practices will enable the production of higher-quality, interoperable datasets, fostering a deeper understanding of bee populations and trends over time. This special issue series of *Journal of Melittology* presents six articles outlining standardized protocols and data standards to support wild bee data collection efforts, together with this article, which makes a general argument for greater standardization. These protocols are applicable to a wide range of research efforts to maximize the quality and use of wild bee occurrence data and can also be integrated into formal monitoring programs. Here, we first outline the need for, and an overview of, a series of standardized protocols and data standards developed in association with the U.S. National Native Bee Monitoring Research Coordination Network. We provide guidance on how to decide among the protocols to achieve different objectives. We then summarize key features of the protocols, including (i) how they are designed to focus on collecting only essential information, while also providing additional recommendations; (ii) that they are intended to be embedded within whatever broader sampling schemes have been designed to meet individual project or program objectives; and (iii) their emphasis on data standards. Lastly, we argue for the collection of additional ecological information that can be used to contextualize wild bee occurrence data. This information supports hypothesis testing to better understand the causal drivers underlying the status and trends of wild bees.

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INTRODUCTION

Wild bee research and conservation efforts worldwide have increased in number and geographic coverage in recent years. In some parts of the world, this has resulted in collaborative initiatives to better understand and protect populations of bees and other pollinators, such as the European Union Pollinators Initiative (https://environment.ec.europa.eu/topics/nature-and-biodiversity/pollinators_en) and the International Union for the Conservation of Nature's Wild Bee Specialist Group (https://wildbees.org/). There have also been increased calls for greater standardization in insect monitoring methods and data management (Montgomery *et al*., 2021) along with formal pollinator population monitoring schemes. Outcomes of these calls include the UK Pollinator Monitoring Scheme (https://ukpoms.org.uk/) and the Distributed System of Scientific Collections (Nelson & Paul, 2019).

In the U.S., wild bee data collection has grown steadily over the last two decades (Rousseau *et al*., 2024) owing to an expanding body of knowledge on pollinator population statuses and an interest in investigating threats and trends (Kremen *et al*., 2002; Potts *et al*., 2010; The White House 2014; Woodard *et al*., 2020). This expansion includes an increasing number of taxonomically or regionally restricted, organized bee data collection schemes in the U.S. These include projects such as the Xerces Society for Invertebrate Conservation's Bumble Bee Atlas projects (MacPhail *et al*., 2024) and state-level wild bee atlases (*e.g*., Vermont Wild Bee Study; Hardy *et al*., 2022, 2023; the Empire State Native Pollinator Survey, Schlesinger *et al*., 2023). Additionally, specimen collections and associated data management at two major federal laboratories (The USGS Bee Lab at the Eastern Ecological Science Center and the USDA-ARS Pollinating Insect-Biology, Management, Systematics Research unit) have also expanded (Ikerd, 2019; Droege & Maffei, 2023; Carril *et al*., 2023). To date, collecting wild bee occurrence data has involved varied and project-specific methodologies for collection, management, and sharing. This stems from projects having diverse and uncoordinated objectives. Thus, using data from these studies to estimate widespread or long-term changes in bee populations or communities is challenging, because datasets are not always widely available and can be difficult to compare.

All properly managed wild bee occurrence data, regardless of whether they are collected as part of a formal program or not, are valuable. Standardized methodologies provide additional benefits, assuming they are compatible with program designs and capacity. First, standardization increases the ability to aggregate and collectively analyze bee data from multiple studies, particularly when they meet FAIR (findable, accessible, interoperable, reproducible) data principles (Wilkinson *et al*., 2016). Data compiled from multiple studies are fundamental for quantifying patterns of bee communities, species distributions, and their dynamics across space and time (Chesshire *et al*., 2023; Dorey *et al*., 2023). Data that are not interoperable (meaning, formatted in ways that allow for aggregation), also hinder conservation-related efforts. For example, as of 2021, only < 0.05% of publicly available wild bee occurrence records report accurate and specific location information, sampling protocol, and sampling effort; yet this information is essential for assessing bee population status and trends (Rousseau *et al*., 2024). Second, data gaps limit the capacity for answering original research questions that may not have been considered during original data collection (Orr *et al*., 2021; Chesshire *et al*., 2023). Third, differences in sampling design can significantly impact the resulting data and inferences drawn from them (Levenson *et al*., 2024a). Descriptions of specific protocols, with sampling effort clearly described, help to ensure that subsequent data users know how data were collected, allowing for adjustment of abundance and richness data to standard sampling effort, and improving reproducibility of published work. Fourth, expert-derived standardized protocols can help guide less-experienced data collectors when initiating new projects. The international honey bee research community has developed a series of standardized protocols that have been widely adopted and cited by honey bee researchers to support their community and make their research more aligned, and thus comparable across studies (Dietemann *et al*., 2013a,b, 2019). We need similar efforts in wild bee research. Fifth, bee data collectors may be able to more readily find funding for their studies, or gain approval for carrying out work, if they have formal plans to follow community-developed standardized methods, such as what we present here.

Within this special issue, we provide standardized protocols for collecting wild bee occurrence data to support the goals of estimating occupancy of focal bee species (Otto *et al*., 2024); collecting community-level bee data (Levenson *et al*., 2024b); collecting plant-pollinator interaction data (Cariveau *et al*., 2024); and collecting bee samples for generating genetic, genomic, and other molecular data (López-Uribe *et al*., 2024) or parasite and pathogen data (Strange *et al*., 2024). We also provide *The Wild Bee Data Standard*, a set of guidelines for wild bee occurrence data management (Du Clos *et al*., 2024a) as well as examples of proper data entry (Du Clos *et al*., 2024b). Within this article, we more fully outline the methods we used to arrive at these protocols. We also provide guidance for deciding among the options and how to use them, and we argue for the importance of collecting additional information that can support hypothesis-testing about the factors that influence bee status and trends, including decline.

METHODOLOGY FOR ARRIVING AT PROTOCOLS

This set of protocols was developed by a subset of members of the U.S. National Native Bee Monitoring Research Coordination Network (hereafter referred to as the Bee Monitoring RCN). This project, funded by the United States Department of Agriculture's National Institute of Food and Agriculture, was established in 2020 to connect members of the wild bee research, monitoring, and conservation communities across the United States (and beyond) to develop a more systematic approach to monitoring wild bee populations in the country. To date, the Bee Monitoring RCN includes more than 800 members from diverse institutions including local, state, and federal government agencies, universities, and non-profit organizations. Since 2021, the Bee Monitoring RCN has hosted multiple open workshops, symposia, and meetings with members to discuss key issues relevant to wild bee monitoring and solutions for monitoring these bees at a national scale. One priority of the project was to provide an opportunity for a large group of experts to co-develop standardized protocols that were guided by the work of the Bee Monitoring RCN. A group of dozens of experts from across the U.S. created the set of standardized protocols presented in this special issue series of *Journal of Melittology* by drawing from their own experience and the relevant literature, synthesizing the key information needed for collecting different types of bee data, and working with authors of *The Wild Bee Data Standard* (see Du Clos *et al*., 2024a) on protocol-specific data standards. This expert group was selected because they are among the members of the bee research and monitoring community who have published extensively on wild bee sampling methods, including development of standardized methodologies (LeBuhn *et al*., 2003, 2012, 2013; Droege *et al*., 2016; López-Uribe *et al*., 2017; Woodard *et al*., 2020). We recognize that the group that developed these protocols is a subset of the larger RCN and there are many additional experts in our field who did not participate in the development of these protocols. Wherever possible, however, the protocols directly incorporate general input from the broader member group of the Bee Monitoring RCN, provided during workshops held from 2021–2023. These protocols can be embedded within formal bee monitoring schemes but also used as-needed by any data collection effort. The resulting protocols support collection of occurrence data or specimens for occupancy modeling, community-level bee data, plant-pollinator interaction data, bee samples intended for genetic and other molecular analysis, and bee samples intended for parasite and pathogen analyses. These specific foci were selected because they address many of the primary objectives of federal and state agencies involved in pollinator protection, land managers, and policy-makers, and support the broader wild bee research and monitoring communities.

GUIDANCE FOR DECIDING AMONG THE PROTOCOLS

Before wild bee occurrence data are collected as part of an organized scheme, project goals must be defined. Clearly articulated goals inform which protocols are best-suited to a planned project. Figure 1 provides a decision tree to aid in selecting the most appropriate protocol(s). The protocols can be combined for projects that have multiple goals, or they can be added to in ways that will provide supplemental information. Whether using a single protocol or combining protocols within a single project, the data generated will be interoperable because they all follow *The Wild Bee Data Standard* (Du Clos *et al*., 2024a). For example, someone interested in documenting the number of species occurring in two locations and their associated host plants will follow protocols for community-level data (Levenson *et al*., 2024b) and plant-pollinator interaction data (Cariveau *et al*., 2024).

GUIDANCE FOR USING THE PROTOCOLS

The protocols and data standards provided in this issue are designed to maximize reproducibility, interoperability, and the utility of wild bee data for hypothesis testing and conservation decision-making. Each protocol provides an overview, a set of expert-guided requirements, and best practices to support effective data collection. The protocols focus on components that are described as *core*, or absolutely essential for achieving one's objectives (Table 1); these are methods that need to be used, or data fields that need to be recorded and reported, in light of the purpose of each protocol and current best practices in biodiversity data management. Importantly, information can be beneficial to collect but not meet our definition of *core*. We also provide *recommended* components, which are extremely beneficial to the specific objective(s) of the protocol, albeit not essential (Table 1). Recommended data fields should be provided, if collected, because they greatly increase the quality and potential uses of data, specifically in relation to its originally intended purposes. Lastly, we provide components we describe as *optional* (Table 1). These components would also increase the quality of collected data, but in ways that are less closely related to the specific objectives of a protocol. *Optional* data fields can be provided if collected, and project managers may decide that they are worth the additional effort required to acquire them, depending on their specific objectives. The roles of *core*, *recommended*, and *optional*

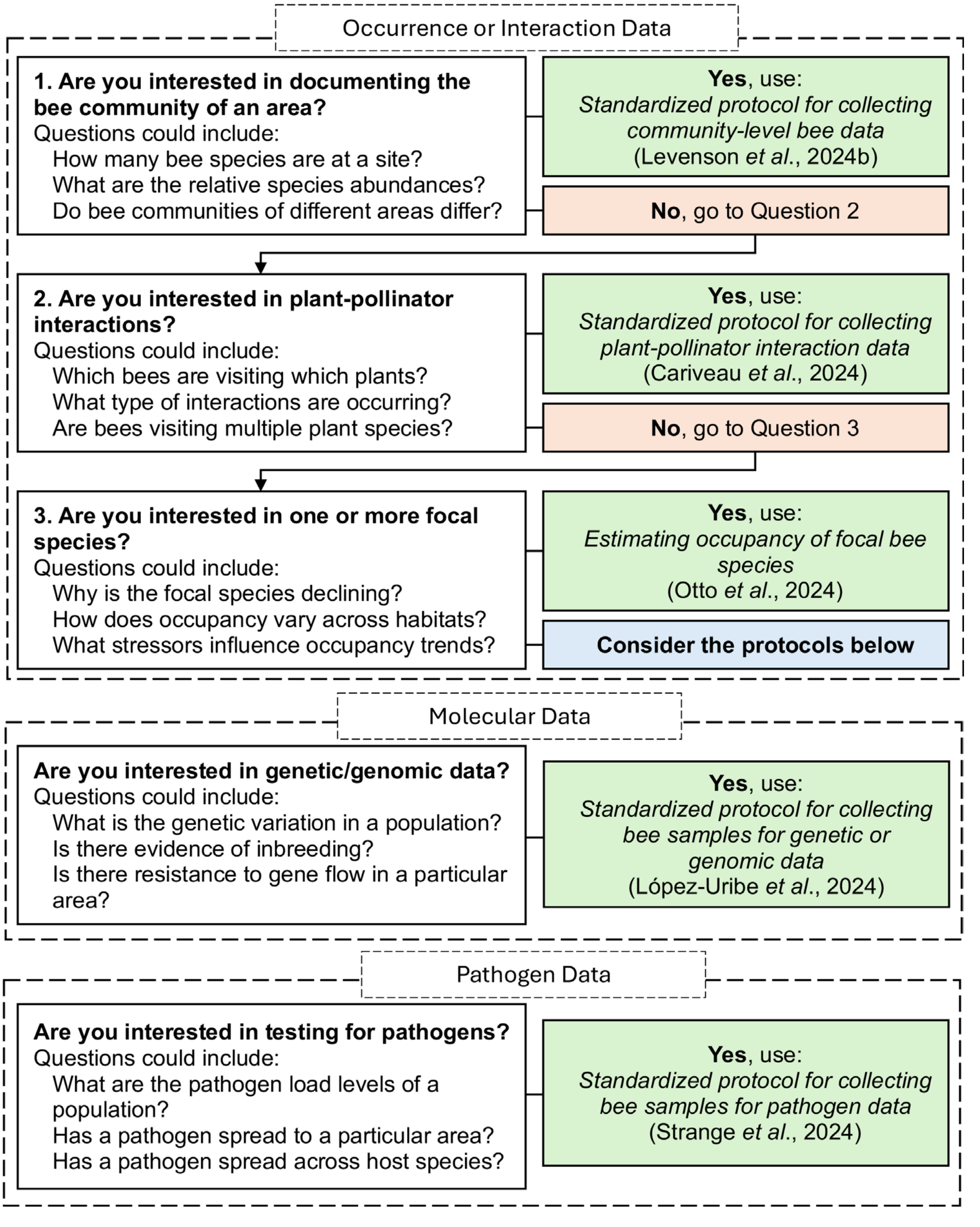

Figure 1. Decision tree for selecting the appropriate protocol based on overarching research questions (in bold) framing the data collection. Standardized protocols must be paired with statistically rigorous sampling frameworks for meaningful results. Specific example research questions are provided below the overarching questions, but protocols can be adapted or expanded to address other questions as needed. Moreover, multiple protocols can be combined within a single project to collect multiple kinds of data.

information when collecting and reporting wild bee occurrence data are expanded on in *The Wild Bee Data Standard* (Du Clos *et al*., 2024a) As an example of the distinction between these terms, our community sampling protocol (Levenson *et al*., 2024b) does not include collection of plant association data as a *core* or *recommended* component. Yet, this is inarguably valuable information for studying relationships between bee and plant communities and it can optionally be added using our plant-pollinator protocol (Cariveau *et al*., 2024). Similarly, the protocol for collecting specimens for pathogen analyses provides the recommendation to collect honey bee specimens to better understand pathogen spillover between bee species at collection sites. Such data might be especially important given the increasing evidence supporting pathogen spread from honey bees to wild bee species (Tehel *et al*., 2016; Mallinger *et al*., 2017). In a few instances, the protocols contain specific requirements that were subjectively decided on by the protocol authors. Examples of this include the site size categories in Cariveau *et al*. (2024) and the minimum number of passive traps deployed in an array in Levenson *et al*. (2024b). Protocols state when decisions were made subjectively and provide justification for them. All protocols require users to report the sampling protocol, describing the method(s) used for sampling, and sampling effort, including amount of time spent sampling and area sampled. These two last pieces of information are extremely valuable (Montgomery *et al*., 2021) but are rarely reported in data shared with public data repositories (Rousseau *et al*., 2024).

We recognize that data collection is generally expensive, time-intensive, and it is carried out by collectors with a wide range of experience levels who need to know which aspects of protocols are absolutely necessary for their primary objectives. The protocols can be expanded and made more complex, but if their *core* components are carried out as-is, they will generate the data required to address the specific objective (for example, characterize the bee community in an area) that the protocol is designed to help achieve. We highly recommend seeking out additional resources generated by the bee monitoring community, including *The Very Handy Bee Manual* (A Collective, 2024), which provide more specific bee sampling methods and techniques. These resources provide detailed information, including recommended materials and purchasing sources, that supplement our standardized protocols.

Table 1. Summary of the protocol structure. Examples are provided based on the protocol for community-level data (Levenson *et al*., 2024b).

Protocol Component	Definition	Example
Core	Practices that are essential for achieving one's objective(s) and need to be used to meet the purpose of the protocol.	Record and report length and width of transect used.
Recommended	Practices that are extremely beneficial, but not essential, to the specific objective(s) of the protocol.	Sample within 1 meter to either side of the transect.
Optional	Practices that can be followed and may be worth the additional effort required, depending on one's objective(s).	Record and report plant association information.

IMPORTANCE OF COLLECTING ADDITIONAL INFORMATION

We re-emphasize the value of collecting optional data fields that provide ancillary information to better understand bee natural history, ecology, and drivers of changes in status and trends. Hereafter, we refer to this simply as "additional ecological information", but we are specifically referring to what might be divided into *natural history information* and *stressors.* The first is natural history information that is more centered on a species' needs, such as the soil type for ground-nesting bee nests. *Stressors* refer to environmental conditions that might cause stress or harm to bees, such as pesticide use, habitat quality (*i.e.*, quality of resources used for nesting, foraging, overwintering, etc.), habitat connectivity, air quality, pathogens, competitive interactions, predation, evidence of parasitism, extreme weather events, and information about collection, harvest, and commercialization. This additional ecological information helps to contextualize wild bee data and will support analyses to understand factors that influence the status and trends of wild bees.

Ecological information can also be integrated into sampling frameworks to improve their design. For example, to develop an effective occupancy-based monitoring program, some basic aspects of a species' biology must be known, such as where they might occur, when they are generally active (time of day and seasonality), and their host plants. With time, the program will also generate additional information about these variables that might shape data collection strategies and can be integrated into analyses to understand drivers of occupancy. Ecological information can be used to inform conservation status assessments, including species status assessments (or SSAs), carried out by the U.S. Fish and Wildlife Service to assess species viability and inform Endangered Species Act listing decisions. This information can also be used to develop or refine conservation and management plans.

UNIQUE FEATURES OF PROTOCOLS

The Bee Monitoring RCN protocols are flexible and adaptable into any number of sampling frameworks. Protocols generally omit details describing some crucial components of bee sampling frameworks, as they are heavily dependent on the broader goals of a data collection project or initiative. For example, the protocols do not provide information about the number of sites that should be visited for deploying them because that choice is dependent on the project question(s), the total study area, and the number of habitat types and how they are defined. When applicable, the protocols offer guidance on key considerations for designing effective sampling frameworks, supplemented with references to exemplary studies. We strongly encourage users to consider analyses to be performed during the project design phase to develop sampling frameworks that are statistically rigorous and will ultimately allow users to test hypotheses with their data.

The protocols heavily emphasize FAIR data principles (Wilkinson *et al*., 2016) and align with the Darwin Core standard (Wieczorek *et al*., 2012), two leading data management frameworks in biodiversity informatics. Data standards have not yet been incorporated into standardized bee protocols, but their importance is increasingly recognized by the bee biodiversity and broader data science communities (Montgomery *et al*., 2021; Rousseau *et al*., 2024). We provide additional information about standardizing wild bee occurrence data in *The Wild Bee Data Standard* (Du Clos *et al*., 2024a). Here too, *The Wild Bee Data Standard* aims to provide guidance for how to treat bee data in the most efficient and effective ways to align with best practices, while avoiding unnecessary complexity. *The Wild Bee Data Standard* is also aligned with existing federal government efforts to increase data transparency and standardization, such as the Biotic Observation Minimum Specification for Fish Wildlife Service Refuges Inventory and Monitoring Surveys (BOMS; US Fish and Wildlife Service, 2023), and initiatives within the U.S. Department of Agriculture and U.S. Department of the Interior, such as the Bureau of Land Management's Strategic Plan for Pollinator Conservation (Bureau of Land Management, 2022). All Bee Monitoring RCN protocols adhere to *The Wild Bee Data Standard*. Importantly, these standards can also apply to bee data that are not collected using these protocols or associated with any standardized sampling scheme.

INVENTORIES, SURVEYS, AND MONITORING

The protocols were designed with an eye towards collecting data needed to detect changes in bee statuses and trends over time. This goal is best supported by repeatedly applying the standardized protocol over time either within a project or among subsequent projects that duplicate at least *core* elements of the protocol. Sampling schemes also need to be statistically rigorous and have the power to detect meaningful patterns through hypothesis-testing. Where applicable, the protocols outline how to collect data for *inventories*, *surveys*, and *monitoring* efforts. We define, here, *inventories* as an attempt to build a species list for an area, not standardized for space or time; *surveys* as an attempt to record data of an area, standardized over space and/or time; and *monitoring* as an attempt to record changes in community measures over time, employing a consistent and repeated protocol, standardized over space and time. When possible, the protocols provide methods for both lethal and non-lethal data collection, however, currently there is a much stronger emphasis on lethal collection methods. Those collecting wild bee occurrence data hold mixed opinions about lethal collection. Potential risks include unintentionally harming study populations through over-collection (Gibbs *et al*., 2017, but see Gezon *et al*., 2015), whereas benefits are being able to confirm species identity, increase statistical rigor, and the ability to store specimens in perpetuity (LeBuhn *et al*., 2013; Turney *et al*., 2015). Presently, to achieve most of the specific goals outlined by the protocols while also having high confidence in species identity, some lethal sampling is still necessary. As methods for non-lethal collecting, such as automated image recognition of unique bee species and eDNA surveillance, become more developed, these protocols can–and should–be revisited and updated to minimize lethal collection as much as possible (Montero-Castaño *et al*., 2022).

We include recommendations in the protocols that can help to minimize over-collection and improve data quality, such as avoiding the use of blue vane traps that bias collections and increase the risk of over-collecting of particular bee groups (Acharya *et al.*, 2022).

CONCLUDING REMARKS

Here, we outline the need for, and provide an overview of, a series of standardized protocols and data standards developed in association with the U.S. National Native

Bee Monitoring RCN. The protocols and best practices provided will be updated and refined through time, for example, as new technologies and approaches are developed. This will be especially true for all protocols as methods for non-lethal data collection continue to improve. We expect this will be most frequent for the protocols for collecting samples for genetic and other molecular data (López-Uribe *et al*., 2024), and parasite and pathogen samples (Strange *et al*., 2024), as these are rapidly changing research areas. We anticipate publishing updated protocols in the future and the articles will be linked so that specific editions can be referenced. Moreover, as new approaches are developed, such as eDNA or AI camera-based data collection, entirely new protocols may be developed. There are additional data collection goals–such as estimating wild bee abundance, nesting resources, and data collection for threatened species–that are not addressed by the current protocols. These will be developed into standardized protocols in the future and connected to this collection of protocols to guide wild bee monitoring.

Another frontier, from the perspective of the U.S. National Native Bee Monitoring RCN, is to work collaboratively with the wild bee research, monitoring, and conservation communities to implement these protocols and integrate them into sampling schemes that best meet their data collection needs. We recognize that field-testing of these protocols and their scalability (Carvell *et al*., 2016), and assessments of their costs and benefits (Breeze *et al*., 2021), are additional next steps that are important for helping our community make decisions about their implementation. The process of integrating these protocols into formal sampling schemes need not be linear; as data are generated and used for hypothesis-testing, this can continually inform actions (such as conservation interventions) and lead to improvements or modifications in sampling design.

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