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Standardized protocols for collecting data on bee-flower interactions and the associated floral community

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Abstract. Pollen and nectar from flowers constitute the primary food resources of bees, inextricably linking bee and flowering plant communities in space and time. Thus, our understanding of bee biology and distribution can be greatly enhanced by documenting interactions between bees and their host plant species. Plant-pollinator interaction data are routinely collected in studies with diverse research goals, but the lack of standardization in data collection has limited our ability to integrate datasets and address outstanding questions in bee ecology, conservation, and pollination biology. Here, we provide standardized protocols for (A) documenting bee-flower interactions and (B) quantifying associated floral resources available to foraging bees. These protocols can be combined for a more detailed understanding of bee-flower interactions and can be applied in *inventories*, *surveys*, and *monitoring* programs of bees. We also provide case studies demonstrating their application. We discuss tradeoffs that are inevitable in any methodological approach, including the use of lethal versus non-lethal sampling approaches, and highlight the need to prioritize rigorous testing of the scalability and generalizability of current methodologies. These protocols are part of a series developed in association with the U.S. National Native Bee Monitoring Network to standardize bee monitoring practices.

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INTRODUCTION

Quantifying interactions among bee species and the flowers on which they forage is critical for understanding and advancing bee conservation and pollination biology alike. Flowers provide bees with nectar and pollen necessary for survival and reproduction. Thus, knowing which plant species individual bee species use and prefer across their flight seasons is central to supporting bee populations. Matching floral use to bee species can also inform how generalized a species is in its diet and reveal the identities of alternative floral resources. Both of these aspects determine species' resilience to landscape transformation, habitat loss, competition, and climate change. In addition to the importance of flowers for supporting bees, bees provide flowers with essential pollination services. Bees' functional role as pollinators of wild plants and managed crops is a primary justification driving bee conservation worldwide (Ollerton *et al*., 2011; Hanley *et al*., 2015; Siopa *et al*., 2024). Quantifying the frequency and timing of bee visitation to flowers allows us to make inferences regarding the importance of different bee species for the pollination of plant species of interest (*e.g*., Winfree *et al*., 2007). Currently, due to the relative paucity of empirical studies providing detailed measures such as pollen deposition from single bee visits, patterns of floral visitation form the foundation for understanding bees' functional roles as pollinators (Vázquez *et al*., 2005). Thus, direct observation of plant-pollinator interactions provides a pathway for understanding a variety of ecological and evolutionary processes, including pollination, resource partitioning, trait matching, phenology of communities and their interactions, community robustness, and biodiversity maintenance, which in turn serve as foundational knowledge for evidence-based conservation and management efforts.

Historically, data on the interactions between bees and flowers have been obtained through largely opportunistic, or otherwise unstandardized, collections of bees on flowers (Burkle *et al*., 2013). These methods provide important insights that, when accumulated, can be used to infer general host associations (Hurd *et al*., 1980; Fowler, 2016; Fowler & Droege, 2020; Smith *et al*., 2023). Such opportunistic collections, however, often lead to biased representation of certain interactions depending on factors such as the season of collection, and thus may result in over- or under-reporting of some species and their functional importance as either hosts or pollinators. Additionally, even datasets collected using more standardized methods, such as those in the recent proliferation of studies of plant-pollinator network structure (*e.g*., Bascompte & Scheffer, 2023), often lack quantitative measurements of the abundance of flowering plants available to bees (Vázquez *et al*., 2007). Floral abundance and diversity often show strong relationships to bee community metrics (Potts *et al*., 2003; Lane *et al*., 2020; Gerner & Sargent, 2022; Torresani *et al*., 2023). Furthermore, quantifying floral abundance for each plant species at the time bees are collected allows for interpretation of host plant preferences that underlie bee-host plant associations (Vázquez & Aizen, 2003; Williams *et al*., 2011). Thus, standardized assessment of floral communities, combined with characterizing flower use by bees, provide fundamental information to land managers selecting plant species for conservation, management, and restoration efforts (Harmon-Threatt & Hendrix, 2015; Williams *et al*., 2015).

Here, we present standardized protocols for collecting bee-plant interaction data. We recognize that individual research teams may work in different ecological contexts and have diverse goals for documenting patterns of floral visitation by bees, and therefore we do not prescribe rigid parameters for study design. Rather, we

propose a set of *core* metrics for which to record how data collection is performed, such that future researchers can utilize the data to the fullest extent. In particular, it is necessary to report metrics such as floral resource abundance and survey effort (*e.g.*, size of search area, amount of time spent searching) so that those wishing to combine multiple independent datasets in meta-analytic or synthetic frameworks may do so without having to make assumptions that may lead to incorrect inferences. Properly documenting the *core* metrics we propose will allow researchers, managers, and agencies to achieve their specific goals (*e.g.*, evaluate the importance of different host plants and bloom phenology) while simultaneously generating interoperable data across collections to understand plant-pollinator interactions better over greater spatial and temporal scales. In the face of declining pollinator populations, the ability to combine robust data on floral host use among studies is fundamental to understanding broader-scale changes of species and communities in responses to climate and land use and other persistent environmental drivers. Moreover, documenting patterns of interactions informs strategies for how we can help mitigate these impacts.

Below, we present two standardized protocols to be used in combination:

Protocol A: Collecting bee-flower interaction data, specifically the species identities and relative abundances of interactions among blooming flowers and bees at a given location. Here, an interaction between a bee species and a plant species is inferred when a bee has been collected from (or observed on) a flower.

Protocol B: Collecting community-level flower data. This involves recording blooming flower species at the location where bee sampling took place, including estimated flower abundances (in floral units), which can be used to estimate floral resource availability for bees and other pollinators at the location, and also their relative preferences among resources standardized by resource abundance.

These protocols assist in the design and implementation of *inventory*, *survey*, or *monitoring* projects of bees with the goal of generating standardized, interoperable data on bee interactions with floral resources (Protocol A) and the availability of floral resources for bees at the same location (Protocol B) (Du Clos *et al*., 2025; Levenson *et al*., 2025). We summarize *core, recommended,* and *optional* data collection and practices of these protocols (Table 1, Appendices 1–3). We define a bee-flower interaction as occurring when a bee contacts the reproductive parts of the flower or is extracting resources through behaviors such as nectar robbing. Time permitting, it is *optional* for the collector also to record more detailed behavior of the bee when visiting the flower (*e.g.*, collecting pollen, imbibing nectar).

Depending on sampling design, information generated by following these protocols can be used to make ecological inferences, including individual bee species' diet breadth, floral choices and preference, and the phenology of bee-flower interactions. Note that the bee-flower interaction protocol (Protocol A) addresses individual visits and cannot be used to calculate the rate of visitation from either the bee's or the plant's perspectives, which may be important variables for some studies. Protocol A will generate bee community-level data, but these data will be specific to bees actively visiting flowers; for sampling entire bee communities, irrespective of whether bees are visiting flowers, a protocol is provided in Levenson *et al*. (2025b; this special issue). Protocol A can also be used to generate lists of bee visitors to flowers in an area. Although we focus on bee visitors to flowers, this protocol can be used in studies that aim to sample broader groups of insect flower-visitors (flies, butterflies, etc.) by modifying it to meet taxon-specific differences in data collection. Protocol B is

Table 1. This protocol is part of a series developed in association with the U.S. National Native Bee Monitoring Network to standardize bee monitoring practices. These protocols include three components of data (*Core, Recommended*, and *Optional*), which are outlined for three strategies of data collection (*Inventory, Survey*, and *Monitoring*). Details in Levenson *et al*. (2025a).

Levels of Data Collection and Reporting		
Core	*Recommended*	*Optional*
Practices that are essential for achieving one's objective(s) and need to be used to meet the purpose of the protocol.	Practices that are extremely beneficial, but not essential, to the specific objective(s) of the protocol.	Practices that can be followed and may be worth the additional effort required, depending on one's objective(s).
Strategies of Data Collection		
Inventory	*Survey*	*Monitoring*
An attempt to build a bee-flower interaction list for an area, not standardized for space or time.	An attempt to record data of an area, standardized over space and/or time.	An attempt to record changes in community measures over time, employing a consistent and repeated protocol, standardized over space and time.

meant to estimate food resources available to bees (*i.e.*, floral abundance and diversity) within the immediate area in which Protocol A is carried out. As such, Protocol B may not be appropriate for estimating overall floral resource availability at the level of the site in which Protocol A is embedded (unless coupled with robust methods such as stratified random sampling of quadrats or transects distributed at the site level), since Protocol A focuses effort on flower patches or other areas enriched with floral resources.

PROTOCOL METHODS

Protocol A: Bee Sampling

Sampling scheme. Where to sample: For these protocols, as in the protocol for collecting community-level bee data (see Levenson *et al*., 2025b), we are defining terms as follows. A *site* is an area of interest of any size, containing one or more plots or transects (Fig. 1), that may contain multiple habitat types. The site may be, for example, an entire location to which a treatment was applied (*e.g.*, hedgerow planting, an area managed through grazing or burning, or restoration site). Site selection is among the most important and time-consuming steps of sampling design if a researcher is interested in ultimately using their data to make general inferences (*e.g.*, the effect of logging on plant-pollinator interactions), as poor site choice can limit or even negate study findings (Eigenbrod *et al*., 2011). Details of site selection are beyond the scope of these protocols and are highly dependent upon the goal(s) of the study. It is critical, however, to ensure sites are independent, not spatially autocorrelated (*e.g.*, sites assigned to specific treatments are not clumped in a specific area), encompass the range of variation in predictor variables appropriate to the specific questions (*e.g.*, site size,

surrounding landscape) while not significantly varying in factors that may impede meaningful comparison across sites (*e.g.*, underlying geology or hydrology), and are numerous enough to have the power to detect changes within or differences among sites (Eigenbrod *et al*., 2011; Williams, 2011; Pasher *et al*., 2013; Hung *et al*., 2019a; Bowler *et al*., 2022). Further, because Protocol A calls for hand-netting bees from blooming flowers (see below), sites without blooming flowers at the time of data collection will not have bee-flower interaction data. In these cases, it is still important to document clearly that the site lacks floral resources during the sampling time in question, as it allows for comparison among types of sites, times of season, state of disturbance, *etc*., and thus context for understanding key goals of monitoring bee-flower interactions. In these cases, researchers can report a sampling event at that site with no bee occurrences recorded (Du Clos *et al*., 2025). In some instances, a land manager may be interested in the bee-flower interactions or floral resources at a specific location, rather than making general inferences, and thus can dispense with explicit consideration of site selection protocols. In these cases, however, researchers should refrain from making general inferences over large areas based on these location-specific findings.

A *plot* is an area within a site that could be sampled via linear or meandering *transects* (Fig. 1; Westphal *et al*., 2008) and is located within one habitat type. A *transect* is a sampling path (including length and width), located within one habitat type, that falls within a plot or site (Fig. 1, A versus B). Thus, using plots, transects, or the two in combination (*i.e.*, transects within plots), are alternative ways of organizing data collection with the goal of characterizing the bee and/or floral communities at a site. Establishing and sampling at least one standardized plot and/or transect at each sampling site is a *core* practice for Protocols A and B for *surveys* and *monitoring*, and *recommended* for *inventories*. Importantly, this means that for the goal of *inventory* for Protocol A, single bee-flower interactions provide valuable information where the *core* data fields are bee identity, plant identity, date, and geographic location of the interaction, but without the requirement of documenting sampling effort within

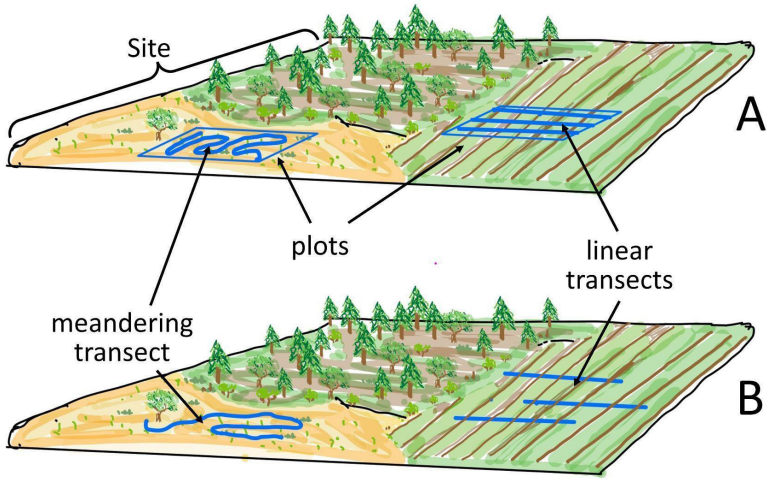

Figure 1. Schematic of sampling scheme showing (A) plot-based approaches with embedded transects and (B) transect based approaches. In both cases these sampling frames fall within single habitat types within the larger site.

delimited spatial areas or time frames. The majority of Protocols A and B generally pertain to methods related to *survey* and *monitoring*, which are plot- or transect-based.

To select plots within a site, we *recommend* following a stratified random sampling design across the site. Stratification involves placing plots across a known gradient or underlying distribution of habitats or environmental conditions (*e.g.*, wetland to upland, wooded versus open areas) within the site. This protocol allows for a deliberate, unbiased representation of the site. Completely random plot placement, in contrast, could also capture the range of environmental conditions, but might require a larger sample size. As long as the choice of exact plot locations within a stratum is random, samples will avoid bias. The appropriate number and distribution of plots within a site will depend on available resources and the question being asked. Theoretically, the number of plots should increase in more heterogeneous sites, but in practice the number employed is often dictated by the amount of time and effort that can be invested. We *recommend* using two categories of plot sizes (see also Levenson *et al*., 2025a): *small plots* (0.01–0.24 h), which can be surveyed in their entirety or nearly so; or *large plots* (0.25–1 h), where researchers can derive informative and representative samples of the overall area using a number of transects (see below). While admittedly somewhat arbitrary, these recommendations are consistent with plot sizes used in the existing literature and represent workable spatial scales for the data collection protocols we outline here. Although it is not a *core* practice of the protocols, for most purposes, keeping plot size consistent across sites within a study is critical for making robust comparisons.

Standard transects are fixed lengths and often (but not always) linear. Typically, standard transects maintain the same location across sampling rounds, although this is not a *core* practice. For meandering transects, observers meander within a plot among floral resources. Meandering transects may sample a greater proportion of the bee community than linear transects (Westphal *et al*., 2008). If a transect is not bounded within an established plot, a *core* practice is to record the length and width of the transect being used and the nature of the transect (*i.e.*, linear *vs.* meandering, randomly placed *vs.* directed). The flexibility that meandering transects allow for may be particularly beneficial in habitats where floral resources have a heterogeneous distribution, as they allow researchers to avoid areas without flowers and thus maximize the amount of time spent sampling from actively flowering plants. Regardless of whether transects are linear or meandering, we *recommend* that within a study, the length and width of transects be kept constant across sites/plots and sampling rounds to facilitate statistical comparison of data. We also *recommend* that time of sampling either remains consistent and/or is recorded to facilitate comparisons across study sites.

It is *recommended* that for small plots (see above) the transect minimum length is 25 m and sampling is performed within 1 m on all sides of the transect for a total minimum sampling area of 50 m^2. For large plots we *recommend* a minimum transect length of 100 m, with sampling performed within 1 m on all sides of the transect for a total minimum sampling area of 200 m^2. Longer transects are *recommended* when possible and necessary (*e.g.*, to capture a representative set of blooming plant species in highly heterogeneous habitats). Splitting a long transect into smaller sections and keeping data separated by section will allow for easier comparison of data with studies and sites that have shorter transects or effort, and calculation of measures of variation.

Transects can be used to sample sites, and the habitats within them, without defined plots. It is a *core* practice of these protocols that regardless of transect type, total transect distance be contained in one general habitat type and that the transect length

or plot area be recorded to allow for standardization of effort and interoperability of the data. For meandering transects, length can be determined using various mobile phone-based GPS applications or more technical GPS receivers.

In some cases, research goals may be better served by allocating approximately equal sampling effort across all blooming plant species within a transect or plot, *e.g.*, when it is important to document the bees associated with rare or rarely visited plant species (Gibson *et al.*, 2011). In Appendix 4, we provide guidance on converting data collected in that fashion into data that are interoperable with our *core* practices.

WHEN TO SAMPLE: The timing and frequency of sampling events will depend on the specific project goal(s) but should consider ecological characteristics relevant to the bee-flower interactions, such as the duration of bloom periods and bee flight periods, environmental conditions that influence when bees would be observed at flowers, and the research and conservation goal(s) of the project. A *core* practice of these protocols is that each plot or transect is sampled a minimum of one time. Sampling more sites less intensively in close temporal proximity better characterizes regional or large site-level patterns of plant use (Bruninga-Socolar *et al*., 2023), whereas repeated sampling within a growing season will be more informative to assess the quality of a site and temporal turnover of bee-flower interactions (Levenson & Tarpy, 2023). Floral resource availability can change over short timescales (on the order of days or weeks). Therefore, if a goal is to compare visitation and/or resources between sites, data collection should happen ideally over a time period that minimizes temporal turnover among bee and floral communities.

We *recommend* including sufficient sampling rounds (temporal replication) required to capture within-season turnovers of bee and blooming flower communities and their interactions within a habitat type. Whether these samples are implemented across replicated sites, or replicated rounds within a site, will depend on geographic region, elevation, season length, and specific project goals. For example, in areas with a shorter active bee flight season, fewer sampling rounds may be required than in areas with a longer active season. If the goal is characterizing the entire bee community, for example, then sampling events are *recommended* across the active flight season of all bee species to capture seasonal differences in the bee and flower communities. If the sampling goal is examining between-year phenological change, for example, the timing of sampling can be selected to coincide with the peak active flight season (if known) or can coincide with phenological events, such as snowmelt or the bloom of a particular plant species. Alternatively, holding the calendar date constant across sampling years may provide information on how bee and plant communities shift their phenologies in response to interannual climatic variation.

Consider that sampling at different times of day at the same site can affect the resulting data as different bee species have different daily activity windows (Fründ *et al*., 2011; Danforth *et al*., 2019). Furthermore, bee activity can be affected by biotic factors such as pollen and nectar availability, and abiotic factors, such as temperature, wind, and moisture on flowers. Thus, it is a *recommended* practice that each site be sampled twice in a sampling round (single day or sequential days), once in the morning and once in the afternoon. Doing so can help to account for this variability and allow one to capture a more complete snapshot of the interactions between bees and flowers.

Recommended conditions for bee data collection are on warm days with clear skies and low to no wind (see Levenson *et al*., 2025b for more details). Practitioners will determine the specific details about sampling site, plot size, transect type, and transect

length for each study, and record these metrics prior to data collection. Although the duration of sampling necessary to obtain sufficient data may vary across contexts, we *recommend* establishing a consistent, predetermined sampling duration for each event prior to data collection to facilitate comparisons across sampling events within the same study. For example, 10 min of active sampling along a 100-m transect has been effective in grasslands (Lane *et al*., 2020). It is a *core* practice, however, to record the sampling duration as a metric of search effort. It is important that the recorded sampling effort only includes the time spent searching for bees; the timer must be stopped after netting and while processing bees or recording data. Therefore, transects with high bee and flower abundance may take much longer to sample compared to transects with low bee and flower abundance. Due to this variation in total elapsed time among sampling events, it is also a *core* practice to record the start and end time of the entire sampling event so that appropriate inferences may be made regarding the activity patterns and foraging choices of the bees that were documented. When sampling, move at a slow, even pace from one end towards the other end of the transect (for both linear and meandering transects). The pace must allow the entire transect to be sampled within the established sampling duration. The observer scans all flowers within a 180-degree radius that are within one meter on either side and one meter in front of the observer.

Type of sampling, lethal and non-lethal: Prior to lethal or non-lethal sampling, researchers need to decide whether to collect honey bees. It is a *core* practice to document whether honey bees are to be collected or not. If honey bees are not collected, collectors must be able to distinguish honey bees from other bee species. In general, we *recommend* netting wild bees only, as processing honey bees (*i.e.*, netting, pinning/photographing, and labeling) can increase the amount of time spent in the field and lab. Furthermore, honey bees can be highly abundant in some areas and thus may constitute a large proportion of sampling effort. If honey bees will not be collected, we *recommend* tallying the number of honey bees seen along each transect, making sure to note the flowers on which the honey bees were observed. Record these numbers on the data sheet by listing the flower species followed by the number of honey bees seen on that plant species. Such data allow researchers and others interested in directly comparing honey bee visits to wild bees to use the data. Time permitting, researchers might want to mark honey bees to ensure that individuals are not recounted. A *recommended* alternative practice would be to collect honey bees, record the plants they were foraging on, keep them in a cooler, and then release them when sampling is complete. This would eliminate the potential of double counting honey bees within a sampling event. Note that some other insects (*e.g.*, some flies and wasps) closely resemble bees; thus, we *recommend* netting or tallying all insects suspected to be wild bees.

Lethal sampling: One of the most critical considerations when implementing lethal collection is ensuring specimens are accurately identified and properly curated. A *core* practice of this protocol is that a plan for bee specimen identification and storage is established *prior* to starting data collection. This includes ensuring the identification expertise, funding, and resources required to identify, curate, and maintain collected specimens are all in place (see Packer *et al*., 2018). This plan should be reported with bee records following *The Wild Bee Data Standard* (Du Clos *et al.*, 2025).

When a bee is observed on a plant, the observer captures the bee, immediately pauses the timer, and transfers the bee into a collecting vessel (*e.g.*, a jar or vial containing ethyl acetate or another euthanizing agent). Once transferred, the vessel is labeled with the plant species from which the bee was collected. All bees caught from that plant species within the plot or transect during the same sampling event can be placed in the same collecting vessel for temporary storage, if project goal(s) allow. A *core* practice is to record the most precise taxonomic rank possible for plants. Typically, this would be plant genus and plant species. For each plant species from which bees are collected, we *recommend* taking four photos of one representative plant as a voucher: one photograph of a single flower looking down on the petals, one photograph from the underside of the flower, one capturing details of the stem and leaf, and one of the whole plant. This series of photos can be used to identify most plants to the level of species. We *recommend* adding photo vouchers to established online platforms (*e.g.*, iNaturalist, observation.org). For an example of how to use iNaturalist to document this information, refer to The Oregon State University Master Melittologist program (https://extension.oregonstate.edu/master-melittologist).

We suggest using the following workflow for processing specimens in the field when following this lethal-sampling approach:

First, fill out a sample label and place one in each collecting vessel. The information should include site, date, plot and/or transect number, site, start and stop time of the sampling event, and collector's initials. We note that most of this information can be pre-printed onto small paper labels ahead of the collecting date for more efficient labeling in the field.

Second, once all individual specimen containers are labeled with plant data, collect and transfer them into a labeled plastic bag (representing one sampling event).

Third, in the plastic bag place a card with the following information: date, site, capture method (netting), and initials of the collector(s). If more collecting will occur, place the bag in a cooler with ice or an ice pack and repeat this process.

An *optional* practice is to handle specimens in a way that will allow them to be used for studying pollen carried on or adhering to bee bodies, or for ectoparasites; in these cases, the bees must be individually collected into separate containers to avoid cross-contamination from one bee to another. Samples that are not collected in this way cannot be used to study pollen or ectoparasites because of the potential for transfer when specimens come in contact with each other in collecting vials (see Strange *et al*., 2025; this issue).

NON-LETHAL APPROACH: For non-lethal data collection, methods may emerge with new technologies and wider adoption among the community of bee enthusiasts and researchers. At present, our non-lethal protocol mirrors the structure of the lethal approach and requires stringent approaches to photography (digital imaging) to ensure photo vouchers are of a standard as comparable as possible to physical specimens. It is not a protocol that creates data as coarse morphological groupings but rather is geared at species / morphospecies identification. Nonetheless it is important to recognize there are many bees that cannot be identified to species based on photographs; such species will thus go unrepresented in datasets generated using this approach despite being photographed (Turley *et al*., 2024). This will limit inference regarding some measures of community change (*e.g.*, diversity metrics, turnover, etc.) and will be biased towards bees that can be identified from photographs or on the wing. For a number of goals, a

non-lethal image-based approach might be best suited for certain bee groups such as bumble bees and other groups that can be identified accurately by sight. It is possible to combine lethal and non-lethal approaches within the same study (See Case study 1). Further, some bee species are distinct enough to be identified on the wing and can be treated in a manner similar to honey bees (see above).

When a bee is observed on a plant, the observer captures the bee, immediately pauses the timer, and then transfers the bee into a clean collecting vessel. In cases where multiple bees are visiting the same plant species in a transect or site, if not collecting specimens for pollen or ectoparasites (Strange *et al.*, 2025), it is an *optional* practice to capture multiple individuals in the same net sweep and chill them together in a larger container. Once transferred, the vial is labeled with the plant name (as outlined above) and placed into a cooler for a minimum of 10 min to immobilize the bees. In our experience, long periods on ice of even two hours will not harm bees (see Oyen *et al.*, 2021). Bee species inhabiting different environments vary in their cold tolerance (Gonzalez *et al*., 2022), and some species may be more prone to chill-induced injury or mortality than others. Since thermal tolerances are unknown for most bee species, and even more so their responses to and recovery from cold immobilization (*e.g.*, Wilson *et al*., 2006; Frost *et al*., 2011), we *recommend* that researchers perform pilot observations of how species in their targeted bee communities respond to cold immobilization before subjecting large numbers of bees to this treatment in full-scale studies. When using a non-lethal approach, a *core* practice is that all handled specimens must be photographed, either singly or arranged in neat groups on a plain surface (*e.g.*, ideally neutral, off-white matte background, with a known-sized printed grid), after which they can be released. We *recommend* using established protocols for photographing bees, such as the protocol developed for the Xerces Society of Invertebrate Conservation's Bumble Bee Atlas projects (available at https://www.bumblebeeatlas.org/pages/photography-tips). Note that this protocol was developed and is effective for bumble bees (Colgan *et al*., 2024), but may not be sufficient for other bee groups. As non-lethal methods continue to develop, we expect that protocols will be tailored to specific groups of bees to aid in identification. It is a *core* practice to label any photo vouchers taken in the field to ensure alignment with sampling event data once digitized (*e.g.*, by recording the image filename in a datasheet, or placing a written or printed sampling event identifier next to each bee being photographed).

Once bees are chilled enough to be immobile, an *optional* practice is to hold all bees in a cooler and release them at the end of a sampling event. Another *optional* practice is for collectors to mark their thoraces with a small dot of non-toxic ink and then release them. The ink dot ensures that individual bees are not resampled. After an individual bee has been processed, the timer is started again, and the observer continues toward the opposite end of the transect, repeating the process outlined above if and when another bee is encountered. We *recommend* treating the "digital specimens" (*i.e.*, photographs) generated using this protocol with the same standard of curation as with physical specimens generated from lethal sampling protocols–*i.e.*, reporting information regarding who provided the taxonomic identification of each specimen and where the images are digitally archived. Uploading the images to iNaturalist.org and adding the identification using the platform provides a streamlined approach to accomplish this goal.

Protocol B: Plant Sampling Methods

A *core* practice for *surveys* and *monitoring* is estimating the amount of blooms for all flowering species occurring in the area where bee sampling is performed (*i.e.*, along transects or throughout a plot). Another *core* practice is to collect floral data around the same time (ideally, on the same day) that bee data have been collected using Protocol A. Doing so provides information regarding floral resource composition and availability at the same spatial and temporal scales as the bee sampling. Importantly, if *site-level* floral resources need to be characterized, additional floral data must also be collected at locations where bees are not sampled. In either case, floral units are estimated separately for each flowering species, in logarithmic or quasi-logarithmic quantity bins (Table 2), to enable rapid and interoperable quantification of the diversity and relative abundance of floral resources in the sampled area. An *optional* practice is to assess floral abundance that yields specific density-based estimates of floral units in the sampled area. The appropriate methodology to accomplish this latter task may vary across study systems and research goals, and may include censusing floral units in plots, transects, or quadrats (Appendix 5).

Table 2. Example quasi-logarithmic floral unit bins in a transect-based survey, with corresponding description-based categories provided for comparative purposes. For longer transects, additional categories with higher floral unit quantities may be added.

Categories for a 50–100m transect	Categories for a 100m + transect	Alternative description-based categories	Alternative category definitions
1–5	1–10	Sparse	Seldom occurring and usually occurring as an isolated plant; few total individuals observed
10–50	10–100	Occasional	Scattered plants in low number; sometimes occur in small clumps
50–250	100–1000	Frequent	Many plants observed; species is regularly seen but rarely becomes dominant
200+	1000 +	Very Common	Species occurring in large numbers; can be dominant

To quantify floral units, it is a *core* practice for researchers to walk along the entire bee sampling area (transect or plot) and estimate the floral units encountered in the area. It is a *core* practice that all species in flower be documented regardless of whether bees are observed visiting them or not, since data on the identity and relative abundance of flowers that are not visited are crucial for elucidating foraging decisions and preferences of bees. Floral unit estimation can be done at any time of day but note that some flowers may wilt or close by midday or may not open until mid-morning, making them more difficult to observe depending on the time of day of flower sampling. It is an *optional* practice to record sampling time and sampling effort (*i.e.*, sampling duration and transect or plot area) as doing so may help in planning for how much labor is required for future sampling. If bee sampling methods may cut or trample flowers, we *recommend* estimating floral abundance first, before bees are sampled.

Documenting the unit of measurement constituting a floral unit for each species is also a *core* practice. A floral unit may consist of a single floret (*i.e.*, morphologically distinct flower) or intuitive clusters of florets (parts of inflorescences or whole inflorescences, for example, "flat" inflorescences of certain Apiaceae and panicles of *Lupinus* and *Solidago* spp.). As a guide, we suggest considering these seven flower shape categories, defined and depicted in Appendix 6: Distinct, Spike, Catkin, Composite, Clustered, Flat, and Paniculate. Decisions on what a floral unit consists of depends on practicality–estimating individual florets may be preferable when a plant species presents distinct, unclustered flowers (*e.g.*, *Argemone* spp.) or when it is rare, whereas estimating compound units (*i.e.*, spikes, clusters, panicles) may be necessary when the same species is overly abundant. To ensure interoperability across surveyors and datasets, it is a *core* practice to record floral data that allow for cross conversion—for example, recording the average number of open florets on a spike or panicle when using these aggregate units of floral abundance. Consider the following scenario: a surveyor might estimate the number of *Lupinus* flowers as individual flowers when fewer than 20 individual blooming plants are encountered in a transect, but estimate the number of blooming spikes at a site where several hundred are encountered in a transect; in this latter case, the surveyor would also record the number of individual flowers borne on 5–10 spikes such that the number of individual flowers at the transect might be estimated. It is a *recommended* practice to predetermine the floral units for each species of a specific project prior to data collection. Detailed photographs of representative units of floral measurement associated with each data collection event may also facilitate interoperability. It is important to note that this protocol yields simple estimates of floral abundance for each plant species, and thus generally cannot be used to parameterize some plant-focused metrics, such as plant density or number of flowers per plant, without the collection of additional data outside the scope of this protocol.

A *core* practice of this protocol is that all recorded plant species are vouchered; this can be done with photo vouchers as described in Protocol A, but physical specimen voucher collection is *recommended* for species-level identification. Regardless, it is a *core* practice to report the type of voucher collected and where the voucher can be accessed for verification. Another *core* practice is to report any sources used in plant identification (*e.g.*, *The Jepson Manual* (Baldwin *et al.*, 2012) or a research-grade iNaturalist photo voucher). The taxonomic resolution for plant identification will depend on project goals. Monolecty (specialization on a single plant species) is rare in bees with most specialist (*i.e.*, oligolectic) bee species not distinguishing among congeners (Wcislo & Cane, 1996); therefore, taxonomic resolution at the genus-level is a *core* practice for identifying flowering plants, but we *recommend* species-level identification.

Data recording: The data to record for this protocol include information on bee species, plant species, and floral units. The complexity of bee-flower interaction data presents challenges to establishing universal standards. This is a rapidly changing area and we expect new protocols to emerge. Two recent, ongoing projects working on such standards are the Brazilian Network of Plant-Pollinator Interactions (REBIPP, Salim *et al.*, 2022) and the WorldFAIR Agricultural Biodiversity Standards (Trekels *et al.*, 2023; Drucker *et al.*, 2024). Both initiatives aim to modify the Darwin Core data standard to incorporate terms that describe plant-pollinator interactions. Darwin Core (Wieczorek *et al.*, 2012) is a widely accepted biodiversity data standard used by leading biodiversity

data providers, including the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/), Integrated Digitized Biocollections (iDigBio; https://www.idigbio.org/portal/search), and iNaturalist (https://www.inaturalist.org/). *The Wild Bee Data Standard* (Du Clos *et al*., 2025; this issue) uses Darwin Core terms and describes their application to wild bee occurrence data, with modifications to existing ratified terms to report bee-flower interactions (Table 3). Applying Darwin Core terms to wild bee occurrence data following *The Wild Bee Data Standard* increases interoperability of data across studies. Examples of recorded data associated with the collecting events for the case studies presented below can be found in worksheet and workbook templates provided with *The Wild Bee Data Standard* (Du Clos *et al*., 2024). Although we outline the *core* data requirements in Table 3 (but also see Appendices 1–3), additional data fields can be collected beyond what is outlined if capacity allows.

Table 3. *Core* data fields to be recorded when implementing the bee-flower interaction and floral community context protocols to adhere to *The Wild Bee Data Standard* (Du Clos *et al*., 2025). *These terms also relate to plant data for Protocol B.

***Core* Data field**	**Description**	**Corresponding Darwin Core Term**
	Protocol A	
Protocol used*	Cite this protocol, as well as others used, and note any modifications	**dwc:samplingProtocol**
Latitude/ Longitude*	Location in decimal degrees of where sampling occurred. Use the center of sampling location (*e.g.*, transect or plot)	**dwc:decimalLatitude dwc:decimalLongitude**
Sample Area*	Plot size or transect area in square meters	**dwc:samplingEffort**
Duration of sampling event	Start date/time, end date/time, duration of active sampling	**dwc:eventTime, dwc:samplingEffort**
Number of collectors	The number of people who collected bees by net during a sampling event (optimally record collectors' collections separately)	**dwc:sampleSizeValue, dwc:sampleSizeUnit**
Basis of record	Document whether the record is a physical specimen or a photographic voucher. Can relate to a bee record or a plant record depending on which protocol component is being used	**dwc:basisOfRecord**
Details of the sampling event*	Report transect type (linear or meandering), length, and width, along with other contextual event information. This includes any site treatment and how honey bees were handled	**dwc:eventRemarks**
Bee physical specimen identification information	For lethally collected specimens, report the identity of the specimen, and the personnel and reference sources involved in the identification	**dwc:scientificName, dwc:identifiedBy, dwc:identificationResources**

Bee physical specimen curation information	Provide identifiers (links or codes) for the institution and collection where the specimen is permanently stored. May report in one or multiple terms	**dwc:institutionID, dwc: collectionID, dwc:institutionCode, dwc:collectionCode**
Bee photo voucher information	Provide links or identifiers of photo vouchers, separated by a vertical bar if necessary. For non-publicly held media, please provide the name of the institution that manages the media data	**dwc:associatedMedia**
Plant association	The plant species on which a bee was collected or observed. Report the species ID and the nature of the interaction (Appendix 7)	**dwc:associatedTaxa**
Plant photo voucher information, if applicable	Provide links or identifiers of photo vouchers, separated by a vertical bar if necessary. For non-publicly held media, please provide the name of the institution that manages the media data. This field is core only if the plant a bee occurrence was collected on was photographed as a representative voucher	**dwc:associatedOccurrences**
	Protocol B	
Plant photo voucher information	Provide links or identifiers of photo vouchers, separated by a vertical bar if necessary. For non-publicly held media, please provide the name of the institution that manages the media data	**dwc:associatedMedia**
Plant identification source(s)	Provide citations for any references used to identify a plant record. Additional context for the taxon name may be provided in **dwc:namePublishedIn** or **dwc:nameAccordingTo**.	**dwc:identificationReferences**
Number of floral units	Provides a count for the number of floral units of a species observed at a sampling site; note that these are reported as ranges as data are binned into categories based on counts (Table 3)	**dwc:organismQuantity**
Type of floral unit	Provides the type of floral unit of a species observed at a sampling site (Appendix 6)	**dwc:organismQuantityType**
Details on measuring floral units	Provides context for arriving at floral unit measurements for each plant species for reproducibility	**dwc:occurrenceRemarks**

EXAMPLES OF IMPLEMENTING BEE-FLOWER INTERACTION AND FLORAL COMMUNITY PROTOCOL

Case Study 1. Inventory of Plant-Pollinator Interactions at Federal Sites

A government agency requests an inventory of plant-pollinator interactions (specifically, wild bee floral visitors) in different habitats within the boundaries of their properties. The agency would like to begin with implementing a single-year *inventory*. The agency has restrictions in which, for certain key bee groups (in particular, at-risk bumble bees), lethal collection should be minimized, and any take must be carried out under permit. As a result, the inventory team is preparing a hybrid *lethal-* and *non-lethal* approach to reduce sampling biases.

Before the *inventory* begins, a plan is established for bee physical specimens and photo voucher identification, curation, and storage. A taxon expert who will identify physical specimens is contacted and compensation is agreed to for the work. An accession agreement for the identified specimens is established with a local museum. An iNaturalist project is created to share photo vouchers of both bees and plants, which will allow for verification of field-based identifications. Supplies are prepared based on the number of sites that will be visited in a day. Permitting and permissions are established for each property and protocols are developed in collaboration with staff at each property.

A set of priority sites has been determined in collaboration with the agency that are expected to have high bee diversity, diverse regionally important native plants, and include multiple habitat types. This approach will advance the agency's interest in using the data to inform vegetation management and selection of plant species to support bees at the properties.

A team of two researchers will visit sites on four different sampling rounds distributed over the main growing season of the region to capture phenological turnover of wild bee floral visitors, their floral host plants, and patterns of interaction. During each sampling round, the team will visit two sites per day, sampling at each site in both the morning and afternoon. To estimate relative abundances among wild bee floral visitors, the team will use a meandering transect approach and record the transect length and width. Most sites contain a single habitat type (*e.g.*, montane wet meadow) but some sites have two habitats (*e.g.*, open woodland adjacent to a meadow). In this case, each habitat will be inventoried separately using separate transects. The team will spend one person-hour walking a 400-m meandering transect, netting any bees observed within 1-m on each side in each habitat type. The team will record the start and end times for each sampling transect and will stop the timer when processing netted bees.

All sampling during the visits will be conducted using an aerial net, for which honey bees will be tallied on a datasheet but not netted due to known high abundances at some sites near apiaries. Bumble bees will be assessed using a non-lethal photographic method, and other bee species will be lethally collected. The team has received extensive training on bumble bee visual identification and there is a high degree of confidence in separating them from other bee and flower-visiting insect taxa. Each collector will net bees from flowers. The flower and foliage of one representative of each plant that bees are collected from will be photographed as a voucher from four different views: (i) a single flower looking down on the petals, (ii) the underside of the

flower, (iii) details of the stem and leaf, and (iv) the whole plant. During the morning sampling, while one team member begins collecting bees, the other will quantify floral abundance along the transect. For efficiency and because of time constraints, the team will use categorical estimates of floral units in $\log_{10}$ bins. Exact floral units (spikes, florets, panicles, etc.) will be determined before each sample event and will be kept consistent within a plant species among the four sample rounds. While quantifying floral abundance, one representative of each plant species in bloom, including those from which no bees are observed, will be photographed as a voucher from four different views as described above. All plant photo vouchers will be uploaded to the team's iNaturalist project.

Lethal approach: When a bee is collected from a new blooming plant species along a sampling transect, a plant-specific collection vial will be created and labeled with a unique event identifier containing the date, site and time of sample; the flower species name; and collector initials using masking tape (*e.g.*, AM-SITE1-Date, Plant species, INITIALS). Note that the unique event identifier created here can be used when digitizing the data after field sampling. Each vial will contain a rectangular strip of paper towel (~3 x 6 cm) inserted as a liner to absorb moisture. If the bee is not a bumble bee, it will be euthanized in the field using a cyanide kill vial and transferred to a labeled plant-specific vial. All non-bumble bees subsequently collected from that same flower species along the same transect will be euthanized and placed in this plant-specific vial.

Non-lethal approach: Bumble bee specimens will be handled differently after netting. Here, each bumble bee is transferred to a vial with air holes bearing a number on the cap. A photo of the vial cap is taken next to the flower the bee was collected on, allowing the vial number, bumble bee identity (as visually assessed in the field), and plant identity to be transcribed onto a datasheet. The vial containing the bumble bee is then placed into a wearable cooler carried by the surveyor. Vial caps have a 1-mm air hole in them to allow for air flow. At 10–15 min intervals during the transect walk, the timer will be paused and bumble bees will be removed from the cooler one at a time and placed in a simple light box, or a grooved tray painted flat white, that allows the bee to be quickly manipulated and photographed from (i) top, (ii) front-on-head, (iii) back-of-abdomen, (iv) side, and (v) underside-of-abdomen views. The numbered vial cap associated with each bee will be included in each photo to allow unambiguous association of the photos with the flower interaction data. The bee will then be released after imaging. After completing the sampling day, all photos of bees will be uploaded to the team's iNaturalist project. Photo sets from each specimen will be grouped based on the datasheet.

The team will follow *The Wild Bee Data Standard* (Du Clos *et al.*, 2025) and start with either the worksheet or workbook data template to organize their data, adding in any additional Darwin Core terms needed for their specific project (Du Clos *et al.*, 2024). In their template, each bee specimen collected is assigned a unique **dwc:occurrenceID** and reported as either a physical specimen if lethally collected or a photo voucher if non-lethally collected in **dwc:basisOfRecord**. The following information is provided for each specimen record, or row, in the digitized data: the unique event identifier used to label the collecting vessels (**dwc:eventID**), the date on which sampling took place **(dwc:eventDate)**, the method used to capture the specimen **(dwc:samplingProtocol)**, the location at which the specimen was found

(dwc:decimalLatitude, dwc:decimalLongitude, dwc:fieldNumber) based on the coordinates from a handheld GPS, the full name of the person who collected the specimen **(dwc:recordedBy)**, and the start and end time of the sampling event in which the specimen was collected **(dwc:eventTime).** To document sampling effort fully, each specimen record will provide additional details about the sampling event in which the specimen was collected, including the total sampling area (length * width of the transect) (**dwc:samplingEffort**) and the predetermined duration of active sampling along the meandering transect, reported in person-hours or decimals of person-hours (**dwc**:**samplingEffort**). Ecological context is provided by reporting weather conditions during the sampling event (**dwc:dynamicProperties**) and the habitat type each bee was collected in (**dwc:habitat**). The team reports that honey bees were tallied but not collected in **dwc:eventRemarks**.

The interaction between a blooming plant and a bee will be described with the term **dwc:associatedTaxa**. This term uses a key:value pair to describe the nature of the interaction and the plant species identification. The interaction is described using two controlled vocabularies, one describing the collection or observation of the bee, the other describing the part of the plant where the bee was collected or observed. While *The Wild Bee Data Standard* allows for interactions to be recorded on leaves and stems, all interactions recorded following this protocol will use "flowers of" here. The plant species identification is described with the taxonomic name and any sources used in making the identification. Examples and controlled vocabulary lists for **dwc:associatedTaxa** are provided in Appendix 7, and these details are also provided in *The Wild Bee Data Standard* (Du Clos *et al*., 2025). If the bee was collected on a photographed plant voucher, the link to the voucher plant on the team's iNaturalist project page should be provided in the term **dwc:associatedOccurrences**. If the plant the bee was collected on was not photographed, do not report anything in **dwc:associatedOccurrences**; the relationship established in **dwc:associatedTaxa** is sufficient. To document floral abundance, report the number of floral units in **dwc:organismQuantity**, report the type of floral unit in **dwc:organismQuantityType**, and report any details on measuring floral units in **dwc:occurrenceRemarks**. Example entries for this case study are provided in both the worksheet and workbook templates accompanying *The Wild Bee Data Standard* (Du Clos *et al*., 2024).

Case Study 2. Monitoring of Plant-Bee Interactions to Determine Effect of Prescribed Fire

A graduate student is examining whether prescribed fire affects floral resource abundance and floral use by wild bee communities. The current funding will allow the student to sample 20 sites for three years, hire a crew of three field technicians, contract with taxonomists for accurate bee species identification, and curate bee specimens for long-term storage. There are no protected bee species in the area, and the student will thus use a *lethal sampling* approach for all bee species.

The student works with various land management agencies to select 10 sites that will be burned in the spring every other year and 10 sites that will not receive burn treatment. A burned site will be paired with a nearby unburned site to create distinct site pairs. Sites within pairs will be at least 1000 m apart but within 5000 m. The student ensures that important characteristics (*e.g*., surrounding landscape, soil type, etc.) are relatively similar across all 20 sites. Further, the sites are evenly distributed across the landscape with respect to burn category (burned *vs*. unburned) and thus treatments

are not clumped in one location of study area. The sites are on average 5 ha in size and the habitat type is relatively similar across sites. The student decides to place two 0.5-ha plots randomly in each site. The sites will be sampled four times throughout the year to yield inference representative of distinct floral communities across the growing season. Before the first round of data collection starts, all four researchers will perform the study protocol together at two burned and two unburned sites, and compare their individually collected data (*e.g.*, estimated floral abundances, size distribution of collected bees) to verify that there are no systematic differences across the four datasets that would result in biased interpretations.

Sites within each pair will always be sampled simultaneously, with each site sampled by a set of two technicians, totaling four personnel working on each sampling date. Both plots at each site are sampled twice on each sampling date, once in the morning and once in the afternoon, totaling eight sampling events, four per site, on each sampling date. The date, sampling start time, and sampling end time will be recorded for each sampling event for each plot. During a sampling event, one technician will walk along a 200-m meandering transect for 10 minutes and collect all bees observed visiting flowers within 1-m on either side of the center of the transect. Once a bee is collected, the technician will stop the timer and transfer the bee into a plant-specific collecting vessel (a 50-ml centrifuge tube charged with ethyl acetate). They will record the plant species the bee was collected on, what part of the plant the bee was collected on, and the nature of the interaction. If this is the first time a bee has been collected from a plant species, a plant-specific collecting vessel will be created by writing the name of the flower species from which the bee was collected and the initials of the collecting technician onto a small cardstock label preprinted with a unique event identifier comprised of the site and plot numbers, sampling date, and sampling period (*i.e.*, AM or PM), then placing the label into the collecting vessel before restarting the timer and returning to netting. When another bee is collected from that same flower species during the same sampling event, it is also placed in that labeled plant-specific collecting vessel. When a bee is collected from a new flower species, another plant-specific collecting vessel is labeled. This approach is being used because the student will not be performing any analyses of pollen or ectoparasites on the collected bees. During this time, the other technician will follow this same protocol at the other plot at that site. Once a sampling event has been completed, the technicians transfer all bee specimens collected from each flower species, along with their associated host plant labels, from plant-specific collecting vessels into plastic vials for storage. All the vials are then placed in a cooler. This protocol is repeated in the afternoon following the floral data collection (see below).

Following the morning collection event, the technicians will briskly walk throughout their respective plots and document the abundance of all blooming plant species, at the level of the 0.5-ha plots, in log10-based bins. Whenever possible, they will record floral units as compound inflorescences (spikes, panicles, etc.), taking five photos of haphazardly selected inflorescences so that the number of florets within each floral unit may be calculated, for interoperability across sites. These photos, along with photographs of the foliage and the entire plant, will be uploaded to an iNaturalist project set up for this study to act as digital vouchers to establish plant identity. Additionally, as one of the planned analyses involves examining how host plant density influences bee foraging decisions, the team will also record a more precise, density-based estimate of floral abundance by laying out four 50-m transects after estimating floral abundances at the plot level. Along each transect, they will place a

1x1-m quadrat at 0 m, 10 m, 20 m, 30 m, 40 m, and 50 m, alternating quadrat placement on either side of the transect. This will lead to a total of 20 quadrats per plot. In each quadrat, the observer will count the total number of floral units for each species within the quadrat. Floral units for each species will be determined prior to collecting plant data. In addition, the technicians will measure the dimensions of 10 floral units for each plant species in the study, haphazardly chosen from within the plot. This will then be used to calculate the total floral area for each plant species for each quadrat (number of floral units x mean area of each floral unit).

The team will follow *The Wild Bee Data Standard* (Du Clos *et al*., 2025) and start with either the worksheet or workbook data template to organize their data, adding in any additional Darwin Core terms needed for their specific project (Du Clos *et al*., 2024). In their template, each bee specimen collected is assigned a unique **dwc:occurrenceID** and is reported as a physical specimen in **dwc:basisOfRecord**. The following information is provided for each specimen record, or row, in the digitized data: the unique event identifier used to label the collecting vessels (**dwc:eventID**), the date on which sampling took place **(dwc:eventDate)**, the method used to capture the specimen **(dwc:samplingProtocol)**, the location at which the specimen was found **(dwc:decimalLatitude, dwc:decimalLongitude, dwc:fieldNumber)**, the full name of the person who collected the specimen **(dwc:recordedBy)**, and the start and end time of the sampling event in which the specimen was collected **(dwc:eventTime)**. The plant species the specimen was collected on, and the nature of the interaction is provided in **dwc:associatedTaxa** (see Appendix 7 for full details). If the bee was collected on a photographed plant voucher, the link to the voucher plant on the team's iNaturalist project page should be provided in the term **dwc:associatedOccurrences**. If the plant the bee was collected on was not photographed, do not report anything in **dwc:associatedOccurrences**; the relationship established in **dwc:associatedTaxa** is sufficient. To document sampling effort fully, each specimen record will provide additional details about the sampling event in which the specimen was collected, including the total sampling area (length * width of the transect) (**dwc:samplingEffort**) and the predetermined duration of active sampling along the meandering transect, reported in person-hours or decimals of person-hours (**dwc**:**samplingEffort**). Report the site type (burned or unburned) each bee specimen was collected in in **dwc:eventRemarks**. To document floral abundance, report the number of floral units in **dwc:organismQuantity**, report the type of floral unit in **dwc:organismQuantityType**, and report any details on measuring floral units in **dwc:occurrenceRemarks**.

DISCUSSION

The scientific literature presents a long and rich history of documenting interactions between communities of co-occurring plants and pollinators. The methodologies used in previous studies have ranged from visual observations on single plant taxa with pollinators identified only to coarse taxonomic groupings (*e.g.*, Albano *et al*., 2009; Watts *et al*., 2012), to collection of all floral visitors of an entire blooming plant assemblage (*e.g.*, Alarcón *et al*., 2008; Williams, 2011; Lane *et al*., 2020; Levenson & Tarpy, 2023), with methods tailored variously to address research questions from the plants' or the pollinators' perspective, or both. Many of these studies are couched in the context of examining the mathematical properties of plant-pollinator interactions in an interaction network context (*e.g.*, Carstensen *et al*., 2016; Cirtwill *et al*., 2018). Our intention with these protocols is not to provide guidance on the "correct" way to construct bee-

flower interaction networks, or to dictate aspects of sampling design that can only be decided based on the goals of a particular project. Rather, we provide the bee research, monitoring, and conservation community with fundamental standardized methods and data standards for documenting interactions between bees and their floral host plants, primarily from the bee community's perspective, but also with guidance on better integrating the plant's perspective (Appendix 4). These practices are designed to support existing and future efforts to contribute interoperable floral visitation (and floral abundance) datasets across the diverse disciplines that routinely involve the collection or observation of bees on flowers, and for *inventory*, *survey*, and *monitoring* projects with diverse goals. When separate datasets are collected using the *core* practices we present, we can combine them to elucidate the nature of bee-flower interactions over large spatial and temporal scales and address research questions that range from fundamental natural history (*e.g.*, the list of preferred host plants for a particular bee species over its geographic range) to applications in evolutionary biology (*e.g.*, conservatism in host plant use across congeners) and conservation biology (*e.g.*, key floral communities associated with persistence of threatened bee species), regardless of the initial objectives of the study in question. In addition to data interoperability across studies, documenting the *core* metrics we propose is crucial for establishing the most robust and actionable comparative data. For instance, Thorp *et al*. (1994) had meticulously documented floral visitation patterns and qualitatively scored host-plant preferences of native bees and introduced European honey bees on Santa Cruz Island, California, and were able to draw some qualitative inferences on the impact of partial honey bee eradication on the island (Thorp *et al*., 2000). However, because we lack information on aspects of their methodology that are *core* to the protocols we presented, we are unable to assess quantitatively at the species level—for either plants or pollinators—the repercussions of one of the only successful large-scale European honey bee eradications ever performed (Wenner *et al*., 2009).

One challenge of research on bee-flower interactions is the tradeoff between lethal and non-lethal data collection methodologies. Non-lethal methods often will yield taxonomically imprecise data, which preclude the use of such data for assessing the floral host associations of the full suite of individual bee species in a study system. In contrast, lethal methods may adversely impact bee populations and/or pollination services rendered to plants, potentially altering the pattern of interactions being documented even as individual bees are removed during the data collection period (Brosi & Briggs, 2013). Here, we provide standardized guidelines for non-lethal documentation of bee-flower interactions in a manner that yields enhanced taxonomic resolution compared to observation-based protocols but acknowledge that these non-lethal methods are still in their infancy. At the present, they are time-intensive relative to lethal collecting and may not be practical or feasible in all regions and for all taxa. Photographic vouchers may be sufficient for certain taxa, such as bumble and carpenter bees, but will yield imprecise identification for taxa that traditionally require scrutiny of morphological minutiae—though resolution may improve with advances in both imaging technology and image classification assisted by deep-learning computer vision (Spiesman *et al*., 2024). As such technologies continue to improve, validation of non-lethal methods and vigorous testing of their scalability should be a research priority. More broadly, few studies to date have evaluated whether different methodologies for documenting bee-flower interactions yield different conclusions (*e.g.*, Gibson *et al.*, 2011). Studies to evaluate the degree to which protocols with different sampling

intensity (*e.g.*, sampling duration and frequency, area of coverage), effort allocation decision (*e.g.*, across plant species, transects, sites), and data precision (*e.g.*, floral unit quantification) yield comparable patterns are very much needed.

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APPENDIX 1

Summary of the *core*, *recommended*, and *optional* practices for establishing study sites and sampling timeframes following the plant-pollinator interaction protocol (*i.e.*, both A and B components) in a *survey* or *monitoring* context. Each project will need to decide the specific details used under each component.

Protocol Component	***Core* Practices**	***Recommended* Practices**	***Optional* Practices**
Sampling scheme	Use a sampling plot or transect Sites are spatially independent		
Transects and Plots	Transects and plots are entirely located in one site in one habitat type (Levenson *et al.*, 2025b) Use at least one standardized plot or transect per site and sample event	Select plots or transects within a site following a stratified random sampling design At least one standardized plot or transect for *inventories*	Completely randomized plot or transect placement can be used but may require larger sample sizes to capture the range of environmental conditions
Plot size	Record the plot size	Establish a small plot (0.01–0.24 h) or a large plot (0.25–1 h) (Levenson *et al.*, 2025b) Keep plot sizes consistent across sites	
Transect size	Record transect length and width Record transect type (linear or meandering) and placement (random or fixed location)	A minimum of 25 meters for small plots and 200 meters for large plots Fixed length across sites/plots	Record meandering transect length with a phone-based GPS application or a GPS receiver
Sample frequency	Sample each plot or transect one time at minimum	Sample enough times to capture within-season turnover of bee and blooming flower communities If the goal is to characterize the entire bee community, sample across the active bee flight season Sample each site once in the morning and once in the afternoon in each sampling round	

APPENDIX 2

Summary of the *core*, *recommended*, and *optional* practices for the plant-pollinator interaction protocol specifically relating to bee sampling methods (Protocol A). Each project will need to decide the specific details used under each component.

Protocol Component	***Core* Practices**	***Recommended* Practices**	***Optional* Practices**
		For lethal and non-lethal	
Sampling conditions	Record weather conditions during sampling	Sample on warm days with clear skies and little to no wind (Levenson *et al.*, 2025b)	
Plant interactions	Document the plant species a bee specimen was collected on	Take four photo vouchers of each plant species: one of a single flower looking down on the petals, one from the underside of the flower, one of the stem and leaf details, and one of the whole plant Upload photo vouchers to iNaturalist	
Sampling time frame (for *survey* and *monitoring* only but recommended for *inventory*)	Record start time, end time, and total search time (*i.e.*, excluding specimen handling / data recording time) Pause the timer when netting and processing bees or recording data	Standardize total search time across sampling events	
Targeted taxa	Record how data on honey bees, if present, were collected. Also record if other species were not collected. If a bee species was collected differently from others, detail the method used (*e.g*, tallied on flowers, netted and released after temporary confinement, etc.). For taxa that are released, record sex when possible	Tally the numbers and identities of non-collected bees (*e.g.*, honey bees) observed foraging on each plant species Capture all insects suspected to be bees	

		For lethal	
Physical specimen collection	Once captured, specimens need to be accompanied by labels unambiguously tied to sampling event data in all vessels until pinned in the laboratory Identify specimens to the finest taxonomic resolution possible and deposit them in a collection capable of long-term archival	If project goals allow, place all specimens collected from the same plant species in the same collecting vessel	If specimens will be used to study pollen or ectoparasites, place each specimen in separate containers to avoid cross-contamination
		For non-lethal	
Digital specimen collection (image-based)	Take at least one photograph of all handled bee individual specimens Each photograph needs to be unambiguously tied to sampling event data (write down photo filename in datasheet, or include event data within image frame) Identify photographed specimens to the finest taxonomic resolution possible and safely archive the image files	Use a developed photography protocol, such as those from Xerces Bumble Bee Atlas, to increase likelihood and certainty of species-level identification Upload photo vouchers to iNaturalist	Chill all specimens collected on the same plant species together To reduce double counting, ink dot bees or hold specimens in a cooler until the end of the sampling event (including honey bees) Collect only wild bees

APPENDIX 3

Summary of the *core, recommended,* and *optional* practices for following the plant-pollinator interaction protocol specifically relating to plant sampling methods (Protocol B). Each project will need to decide the specific details used under each component.

Protocol Component	***Core* Practices**	***Recommended* Practices**	***Optional* Practices**
Floral units	For *survey* and *monitoring*, estimate the amount of blooms for all flowering species in a plot or transect, regardless of whether a bee was collected on that species or not Walk the entire plot or transect Use quantity bins outlined in Table 2 Document the measurement constituting each floral unit following Appendix 6 Record floral data to allow for cross-conversion such as average number of open florets on a spike, for example	Record floral abundance before bees are sampled to avoid cutting or trampling blooms Photograph a representative unit of floral measurements associated with each data collection event	Follow methodology outlined in Appendix 5 to perform more detailed floral abundance assessments Record sampling effort
Plant vouchers	Voucher all plant species included in data collection Report if a physical or photograph voucher is used Identify plants to genus-level	Physical specimens may be needed for species-level identification Identify plants to species-level	

APPENDIX 4

An alternative to documenting bee-flower interactions using transects is to spend a standardized, predetermined length of time observing patches of each blooming plant species within a plot (*e.g.*, Gibson *et al.*, 2011; Spiesman & Inouye, 2013; Traveset *et al.*, 2018). This approach may be useful when plots where bees are sampled are highly heterogeneous such that no transect layout would cover all plant species, or when documenting the bees associated with rarer plant species is an important goal (Gibson *et al.*, 2011). We *recommend* spending the same amount of time observing each plant species in bloom and observing multiple patches of each species in intervals of 1 to 10 min per patch. An observation patch should be large enough that pollinator visits to the patch are likely within the observation interval (*e.g.*, a single flower may not be visited within 10 min), but small enough that any bee visiting flowers of the patch can be readily detected and collected without losing track of other bees visiting the same patch. The size of the patch would thus depend on the context of the bee-flower interactions—species with large flowers that experience low visitation rates may have larger patches, whereas densely packed inflorescences that experience high visitation rates may need to have smaller patches. We highly *recommend* keeping the patch size approximately consistent within the species during each sampling event at each site (but not necessarily across sampling events and/or sites). As with the transect-centered protocol, each bee that lands in the patch being monitored is collected and placed in a lethal or non-lethal collecting vessel while the timer is paused.

This equal-effort observation approach results in pollinator data that do not accurately reflect plot-level relative abundances of visitors to rare versus abundant plant species. However, it is possible to correct for the bias towards rarer plants introduced by this approach. To do so, it is necessary to record the number of floral units in each species' observation patches, as well as a more precise estimate of the number of floral units of each plant species within the plot (*i.e.*, more precise than logarithmic-based quantity bins; see Appendix 5). The process for the bias correction is as follows:

First, average across the N rounds of observations at patches of a particular plant species to estimate the average number of blooming floral units (*e.g.*, individual flowers, capitula, panicles) observed in each round (or alternatively, choose a set number of floral units and consistently observe a patch with that number of floral units for each round of observations).

Second, average across the N rounds of observations of the plant species to estimate the average number of individuals of each pollinator taxon visiting an observed patch of that species per observation interval within the study plot.

Third, estimate the number of observation patches of the plant species blooming within the study plot (*i.e.*, divide the plot-level floral unit count by the observation patch-level floral unit count), and multiply this number by the pollinator abundance estimates calculated in the second step. The resulting value represents the estimated number of individuals of each pollinator taxon expected to be visiting all flowers of the plant species per observation interval over the entire study plot.

Fourth, repeat steps above for each plant species in bloom at the study plot to derive corrected relative frequencies of bee-flower interactions at the plot.

APPENDIX 5

The *core* methodology for documenting floral abundance involves estimating the number of floral units within the sampled area in logarithmic or quasi-logarithmic bins. However, certain research questions would benefit from additionally obtaining more precise measures of floral density over the sampled area. The most efficacious method for obtaining these more precise measures may depend on the context, and here we offer two possible methods.

METHOD 1. If there are blooming plant species, one may count floral units in regularly (or randomly) placed quadrats or transects dispersed throughout the study area. For example, consider a 50m x 50m plot where a field technician walks along a meandering transect to collect bees. One way to sample the floral community would be to create two ~71m transects running diagonally across the plot from corner to corner. Along the transect, the field team places a 1m x 1m quadrat every 7m for 20 total quadrats. The field team alternates the placement of each quadrat on either side of the transect. For each quadrat, the team counts the number of floral units that are contained within the quadrats. As much as possible, the team should agree on how to characterize species based on their floral units. If a new species of flowering plant is encountered, the field team should all agree on how the new species will be recorded. The field team also measures the floral units so as to be able to calculate the total area per floral unit. For example, for circular flowers or inflorescences, they will measure the diameter to estimate area per unit. Measurements should be conducted for at least 10 floral units. After the data are collected, entered, and cleaned the number of floral units per species can be multiplied by the average area for that species to calculate the total floral area per quadrat per species. This method provides transect-level estimates for the total floral area as well as each species individually.

METHOD 2. In study systems with highly patchy distribution of blooming plant species, it may not be possible to capture the relative abundance of all plant species using transects or quadrats. In such cases, we *recommend* counting replicates of increasingly larger components of floral units, then multiplying across the averages of all components (*e.g.*, see Hung *et al*., 2019b). For example, count 5 replicates of the number of flowers on a *Lupinus* stalk, 5 replicates of the number of stalks on a *Lupinus* plant, 5 replicates of the number of *Lupinus* in a 1-m^2 patch of *Lupinus*, and the number of 1-m^2 patch of *Lupinus* in the entire sampled area. Then, average the replicate counts and multiply the averages together to derive the estimated number of *Lupinus* flowers at the entire plot. There can be as many nested levels of components as necessary, and the organization of the levels may depend on the context (*e.g.*, number of individuals might be estimated if floral abundance is relatively uniform across individuals, but number of stems or racemes might be estimated instead if individuals differ widely in how many stems or racemes they bear). It may be helpful to divide the plot into quadrants or sectors to facilitate counting plot-level components, and to use a click counter when tracking large numbers.

APPENDIX 6

Example floral morphologies and arrangements, and recommendations for documenting their abundance.

DISTINCT
Example: *Chamaecrista fasciculata*

Each flower has its own pollen structures, is fairly large and easily countable.

Count each individual flower as one floral unit.

Other examples include *Rosa*, *Papaver*, *Potentilla*, and *Penstemon*

SPIKE
Example: *Verbena hastata*

Each spike is a tall structure composed of many smaller, distinct flowers.

Count each independent spike structure as one floral unit.

Other examples include *Melilotus*, *Lupinus*, and *Astragalus*.

COMPOSITE
Example: *Rudbeckia hirta*

Each composite is composed of a central disk of many small florets surrounded by ray petals.

Count the entire composite head as one floral unit.

Note that composite blooms often hold onto their ray petals after they stop producing pollen. Be sure to check the pollen structures in the central disk for pollen before recording it as "blooming".

Other examples include *Helianthus*, *Heliopsis*, *Ratibida*, *Grindelia*, *Madia*, and *Taraxacum*.

CLUSTERED
Example: *Trifolium repens*

Each cluster is composed of many small, often irregular florets. Clusters are most often round or semi-circular. In some cases, these will be hanging down.

Count each cluster as one floral unit.

Other examples include *Securigera*, *Monarda*, *Medicago*, *Lotus*, and *Eriogonum*

FLAT
Example: *Zizia aurea*

Each flat unit is composed of many small, difficult-to-count florets arrayed on a single plane, called an umbel. Since each umbel can have varying numbers of florets, count this type of flower as the number of circles with a 5 cm diameter (about the size of a fist).

Other examples include *Vernonia*, *Achillea*, *Lomatium*, and *Pycnanthemum*.

PANICULATE
Example: *Solidago canadensis*

Each paniculate unit is composed of many small, difficult-to-count florets arrayed on irregularly sized branches, called a panicle, along a single rooted stalk.

Count each individual rooted stalk as one floral unit.

Note that panicle blooms may need to be further categorized into distinct size categories when there is large variation in individual panicle sizes, such that a plant species would occupy multiple entries on the datasheet, where panicles belonging to separate size classes are recorded separately (*e.g.*, recording small panicles ≤ 15 cm, medium panicles ≤ 50 cm, and large panicles > 50 cm as distinct entries).

Other examples include *Symphyotrichum*, *Euphorbia*, and *Hypericum*.

APPENDIX 7

Details for using the term **dwc:associatedTaxa** as described in *The Wild Bee Data Standard* (Du Clos *et al.*, 2025).

DEFINITION: A list of identifiers or names of taxa (in this case, plants) and the associations of this occurrence (in this case, a bee) to each of them.

HOW TO USE: *This term uses a controlled vocabulary.* Using a key:value pair, provide the appropriate relationship from the following list, using a combination of an action and a part of the plant where the bee was found. If using both the plant species and the authority key:value pairs, separate them with a comma. Enclose the entire term with curly brackets ({}, see Examples):

- Controlled vocabulary list for **dwc:associatedTaxa**:
  - Action vocabulary: "Caught on", "observed on", "visits"
  - Plant part vocabulary: "flowers of", "leaves of", "stem of"

Provide at least the genus name of the plant, though the full plant scientific name (*Genus species*) is preferred. We advise reporting the source for the taxonomic name with the authority key:value pair.

- The authority should be a full citation of the source used to identify the plant. Examples include:
  - Flora Novae Angliae. 2011. Yale University Press https://plants.usda.gov/home/plantProfile?symbol=SOCA6
  - The Jepson Manual: Vascular Plants of California. Second Edition, 2012. University of California Press

EXAMPLES:

- {"visits flowers of":"*Rubus*"}
  - For reporting plant interaction only and identifying plant to genus level
- {"observed on flowers of":"*Solidago canadensis*", "authority":"The Jepson Manual: Vascular Plants of California. Second Edition, 2012. University of California Press"}
  - For reporting plant interaction, full scientific name of the plant, and the source of the taxonomic identification of the plant

FOR MORE DETAIL: https://dwc.tdwg.org/terms/#dwc:associatedTaxa

Journal of Melittology

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The *Journal of Melittology* is an international, open access journal that seeks to rapidly disseminate the results of research conducted on bees (Apoidea: Anthophila) in their broadest sense. Our mission is to promote the understanding and conservation of wild and managed bees and to facilitate communication and collaboration among researchers and the public worldwide. The *Journal* covers all aspects of bee research including but not limited to: anatomy, behavioral ecology, biodiversity, biogeography, chemical ecology, comparative morphology, conservation, cultural aspects, cytogenetics, ecology, ethnobiology, history, identification (keys), invasion ecology, management, melittopalynology, molecular ecology, neurobiology, occurrence data, paleontology, parasitism, phenology, phylogeny, physiology, pollination biology, sociobiology, systematics, and taxonomy.

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