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Estimating occupancy of focal bee species

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Abstract. Current bee monitoring efforts have a limited capacity for understanding factors affecting wild bee population changes, including the effects of management. To improve the effectiveness of wild bee monitoring, we first discuss principles of biological monitoring and provide a framework to design monitoring projects to estimate species occupancy, where occupancy is defined as the probability that a Sampling Unit or site is occupied by the focal species. Monitoring practitioners should first define the desired goal or question of monitoring and secondly select the appropriate state variable for monitoring (*e.g.*, species richness, occupancy, abundance). These represent two critical, yet often overlooked, steps in the development of wild bee monitoring projects. As with all forms of demographic monitoring, practitioners who are interested in estimating species occupancy will need to develop a sampling scheme tailored to meet their monitoring objectives. Defining key sampling terms will provide the architecture of their scheme, including the Area of Interest, Sampling Unit, Season, and Replicate Survey. We also highlight data standards, including *core* data fields that must be collected during Surveys for bee occupancy data and additional, *recommended* data fields. We illustrate how these monitoring concepts are being applied to the design of a real-world monitoring project for the federally endangered rusty patched bumble bee (*Bombus affinis* Cresson). This framework was developed in association with the U.S. National Native Bee Monitoring Network.

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INTRODUCTION

Occupancy, defined as the probability that a Sampling Unit (*i.e.,* site, patch, etc., Table 1) is occupied by one or more focal species, is a primary variable of interest for many biological monitoring programs in the United States, including the Amphibian Research and Monitoring Initiative and North American Bat Monitoring Program. It is selected as a state variable (*i.e.,* quantities that describe a state of a dynamic system, at a specific time) for biological monitoring because of its effectiveness in informing management (Weller, 2008; Hamer *et al.*, 2021), understanding species distribution dynamics (Adams *et al.,* 2013), and evaluating species responses to environmental stressors (Grant *et al.*, 2016; Janousek *et al.,* 2023). In addition, the U.S. Fish and Wildlife Service (USFWS) often uses occupancy when establishing demographic goals for species recovery under the Endangered Species Act. More pragmatically, occupancy is often used in wildlife monitoring because it is less costly and time consuming than collecting species abundance data yet also provides meaningful information on species demographic dynamics (MacKenzie & Nichols, 2004; Noon *et al.,* 2012).

Here, we provide bee monitoring practitioners with a framework to design a sampling scheme for estimating species' occupancy across space and time, while also outlining some more general principles required for robust monitoring projects. We provide guidance on monitoring design and assist practitioners with defining key terms that are important for conducting occupancy monitoring. We describe *core* (*i.e.,* required for achieving monitoring objectives) and *recommended* (*i.e.,* additional, beneficial) data fields, though we do not provide specific parameters for these fields, such as recommended Sampling Unit size or Survey duration, because these should be based on individual project goals (Du Clos *et al.*, 2025). For many bee species, relatively little is known about their baseline distribution and natural history, which makes it challenging or impossible to implement formalized monitoring. Some information on the focal species' natural history is required before more formalized monitoring can be initiated (Levenson *et al.*, 2025a). Our target audience thus consists of people or organizations interested in developing monitoring projects for focal wild bee species to understand changes in species occupancy through time or the effect of management or stressors on species occupancy. We recognize that holistic monitoring of wild bees should also include other state variables such as species diversity, population size, and vital rate parameters associated with changes in diversity and population size (Yoccoz *et al.,* 2001). In fact, we note that occupancy often serves as the foundation of other biological monitoring programs in the United States, but these programs also include monitoring of other variables such as species richness, abundance, and survival (Corn *et al.*, 2005; Muths *et al.*, 2005). Practitioners should review additional protocols in this special issue and other published bee monitoring protocols (*e.g.*, Droege *et al.,* 2016) to decide which best fit their monitoring objectives.

Much has been written about designing biological monitoring projects (Yoccoz *et al.,* 2001; Nichols & Williams, 2006; Marsh & Trenham, 2008) and there is a pressing need to incorporate this guidance into wild bee monitoring to generate actionable information for conservation. Otto *et al.* (2025) highlight the broad importance of identifying bee monitoring objectives and state variables and discuss the advantages of integrating occupancy estimation into bee monitoring. Here, we build upon this approach to provide a framework to design a sampling scheme for bee monitoring for estimating species occupancy. This framework consists of the following steps: 1) Identify monitoring objectives; 2) Select the state variable(s) of interest; 3) Design a sampling scheme and define key sampling terms (Table 1); 4) Select field sampling methods; and 5) Select data fields (Fig. 1).

Table 1. Key terms for designing an occupancy monitoring project.

Term	Definition
Area of interest	The space over which monitoring practitioners hope to make inference
Detection	An unambiguous record of the focal species observed or collected during a Survey. A positive Detection may include a physical or photographic voucher
Sampling unit	Discrete location or patch, located within the Area of Interest, where occupancy of the focal species will be evaluated (*i.e.,* a monitoring site)
Season	A time period when the state variable (e.g., occupancy, abundance, species richness) is assumed to be static or unchanged. For occupancy monitoring, a Season is a period when Units are closed to changes in occupancy (*i.e.,* unoccupied Units remain unoccupied and occupied Units remain occupied)
State variable	One or more quantities that describe the state of a dynamic system, at a specific time. For biological monitoring, State Variables include occupancy, abundance, and species richness
Survey	A single sampling event conducted at a Sampling Unit where detection/non-detection data of the focal species are recorded. Multiple Surveys are conducted within a single Season to estimate species detection probability
Target population	All Sampling Units that exist within the Area of Interest. Probabilistic sampling is used to select a subset of Sampling Units for data collection

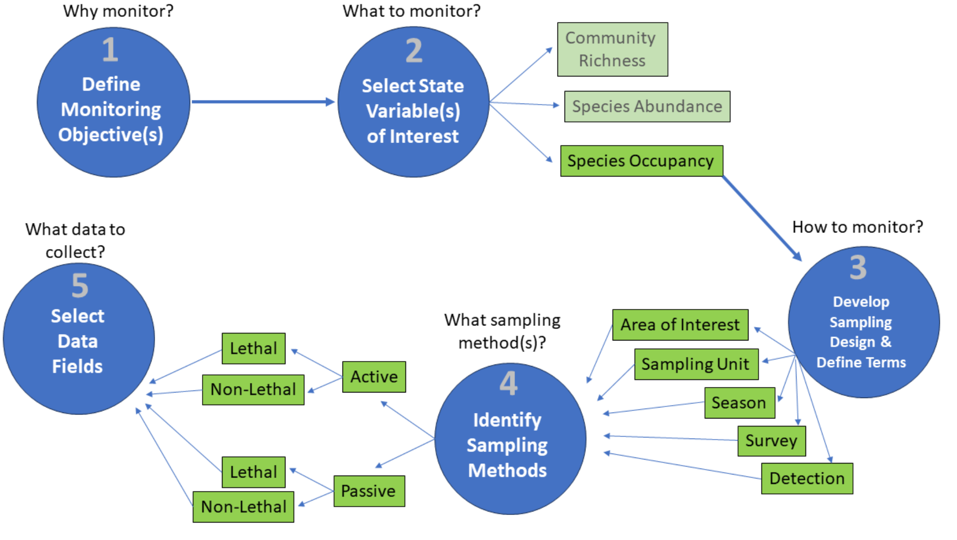

Figure 1. Flow chart for designing a monitoring effort for estimating occupancy dynamics of focal bee species.

We provide practitioners with specific guidance at each step of the framework and address common issues practitioners are likely to encounter along the way. To further illustrate the necessary processes, we also provide a Case Study describing a long-term monitoring project being developed for the federally endangered rusty patched bumble bee (*Bombus affinis* Cresson, Fig. 2), where occupancy is a state variable of interest for monitoring.

Figure 2. The federally endangered rusty patched bumble bee (*Bombus affinis* Cresson) visiting butterfly milkweed (*Asclepias tuberosa* L., Apocynaceae) in eastern Minnesota. Photograph by Clint Otto, USGS.

STEP 1. IDENTIFY MONITORING OBJECTIVES

Before designing protocols for occupancy monitoring (or any form of monitoring), it is important to establish monitoring objectives. Developers of wildlife monitoring programs have stressed that monitoring has its greatest utility when the objectives are clearly defined, the data collection is hypothesis-driven, and it is clear what decisions will be influenced, or what uncertainty will be addressed, through monitoring (Yoccoz *et al.*, 2001; Nichols & Williams, 2006; Sutherland *et al.*, 2009). Experts have challenged practitioners to develop monitoring objectives that either address scientific uncertainty surrounding species demography or assess the impact of management (Yoccoz *et al.*, 2001), as opposed to conducting surveillance monitoring that is not driven by specific objectives. Monitoring objectives can also be strengthened if the desired future state of the system can be identified, such as a desired minimum population size. Whereas general "trend detection" is often used as the impetus for initiating monitoring, once a trend is detected, it often leaves decision-makers wanting to know more detailed, actionable information, such as the ecological drivers of the observed trend, or what population vital rates are associated with the observed trend (*e.g.*, local colonization/extinction for occupancy, individual survivorship, fecundity, and movement for abundance). Thinking hard about monitoring objectives during the early phases of wild bee monitoring can help ensure that priority information needs are met and that years of monitoring effort are not wasted on the collection of data that have little value for achieving specific monitoring goals. This is especially important for rare or declining species that often have time-sensitive monitoring needs. Otto *et al.* (2025) provide working examples of how to develop wild bee monitoring objectives that improve scientific understanding of demographic processes and/or inform management actions. The importance of defining monitoring objectives will become readily apparent when it comes time to design the sampling scheme. This is because decisions about where and when to sample and what data to collect are highly conditional on the monitoring objectives (Fig. 1). Defining monitoring objectives also helps practitioners determine the state variable(s) to monitor and the demographic quantities to estimate. Note that monitoring objectives can be formulated to address multiple areas of uncertainty and will often be accomplished in phases, such as in an adaptive management framework. The multiple phases of monitoring are evident in our Case Study, provided below, where practitioners are interested in first learning about factors that bias estimates of *B. affinis* occupancy, specifically false absences, so that a more robust monitoring project is designed to understand long-term changes in species occupancy.

STEP 2. SELECT THE STATE VARIABLES

Identifying the focal state variable(s) of a monitoring project is the second step in our monitoring framework and is informed by the monitoring objectives identified in Step 1 (Fig. 1). For demographic monitoring, state variables of interest include abundance (*i.e.*, population size), species occupancy, species diversity, and species richness (Yoccoz *et al.*, 2001). Monitoring protocols for estimating bee community properties are published elsewhere in this special issue (Levenson *et al.*, 2025b). Occupancy is often selected as a state variable for species experiencing rapid distributional changes (*e.g.*, range contractions) or for situations where local population size varies dramatically based on life history (Noon *et al.*, 2012). For these species, estimating local abundance or change in local abundance may not be practical or necessary for understanding population changes across broad geographic landscapes. Practitioners may also be interested in drawing inferences about system vital rates that are responsible for affecting change in the chosen state variable. For example, the vital rates responsible for changes in abundance are survival, fecundity, and movement. In contrast, the vital rates that are responsible for changes in species occupancy are local colonization and extirpation. Colonization represents a situation where a Sampling Unit that was not occupied in an earlier period becomes occupied. Systematic colonization of unoccupied Units could, in time, be interpreted as a range expansion. Extirpation, also referred to as local extinction, is when a Sampling Unit that was occupied in an earlier period becomes unoccupied. Systematic extirpation could eventually lead to range reduction, such as in the case of *B. affinis, B. franklini* (Frison), and *B. occidentalis* (Greene) (Cameron *et al.*, 2011; Graves *et al.*, 2020). The remainder of this framework will focus on occupancy as a state variable of interest and the vital rates associated with occupancy (colonization and extirpation).

What is Occupancy?: As mentioned above, occupancy is the probability that a Sampling Unit, patch, or site is occupied by one or more focal species. Occupancy estimates are generated from detection and non-detection data of the focal species (*i.e.*, observed/not observed) during standardized Surveys. These data are commonly referred to as "presence-absence" data; however, inferring absence when a species is undetected is problematic. It is challenging to distinguish between genuine absence and failing to detect the species during one or more Surveys when it is present at a Unit (*i.e.,* false negative). This dichotomy reflects the two processes that affect the outcome of whether a bee species is detected at a Sampling Unit (MacKenzie *et al.*, 2017). The first is the biological process: the Unit is either occupied or unoccupied by the focal species. The second is the sampling or observational process: if the Unit is occupied, what is the likelihood the bee species will be detected during a given Survey or sampling event? Accounting for "false absences" or "false negatives" is a widely understood problem in ecology and biological monitoring (refer to MacKenzie *et al.*, 2017). The solution to this problem is to incorporate detection probabilities in models used to estimate changes in species occupancy across space and time. Occupancy models, fortunately, allow practitioners to estimate occupancy while accounting for imperfect detection of focal species (MacKenzie *et al.*, 2017). For example, occupancy models have been used to estimate occupancy dynamics of Northern Spotted Owls (*Strix occidentalis*) to inform recovery efforts of this federally Threatened species that is also difficult to find in the wild (Olson *et al.* 2005). Occupancy models integrate two conditional logistic regression sub-models to estimate occupancy and detection parameters from detection and non-detection data collected during Replicate Surveys (Royle & Dorazio, 2006).

The sequence of detection/non-detection data recorded for the target bee species is represented as a detection history consisting of multiple (j) Surveys conducted at $i = 1, 2, \ldots N$ Sampling Units. For example, detection histories for N=10 Sampling Units (*e.g.*, restored prairies) that were each surveyed j=4 times during the summer for *B. affinis* may appear as:

Prairie 1: 1011
Prairie 2: 1100
Prairie 3: 1011
Prairie 4: 0000
Prairie 5: 0011
Prairie 6: 1-10
Prairie 7: 00-0
Prairie 8: 0000
Prairie 9: 1000
Prairie 10: 1100

Here, a '1' in a detection history represents a detection of at least one *B. affinis* during a single Survey, '0' represents non-detection, and '-' represents a missing value, indicating the Sampling Unit was not surveyed during a particular Survey or event. For example, at Prairie 2, *B. affinis* was detected during the first and second Surveys but not during the third and fourth Surveys. This detection history is used to estimate occupancy and detection probabilities.

STEP 3. DESIGN A SAMPLING SCHEME AND DEFINE KEY SAMPLING TERMS

Here, we provide practitioners with a generalized approach for designing a monitoring project where occupancy is the state variable of interest. We avoid specific recommendations of sample size (*i.e.,* number of Sampling Units), effort (*i.e.*, area of Sampling Units and Survey duration), and sampling protocol (*i.e.*, employing passive or active methods) because there is no prescriptive, one-size-fits-all approach to monitoring occupancy or other state variables. In fact, particular details of monitoring project design are going to be driven by monitoring objectives, the unique biology of the focal species and study area, and logistical constraints. Our guidance incorporates recommendations associated with estimating species occupancy (MacKenzie *et al.*, 2017) and recommendations from experts who have developed guidance for other wildlife monitoring programs (Yoccoz *et al.*, 2001; Williams *et al.*, 2002; Nichols & Williams, 2006). The Case Study we provide below for *B. affinis* monitoring is an example of using our framework (steps 1-5, Fig. 1) to design a sampling scheme for a monitoring project, but we caution readers that this design will likely not be appropriate for the specific needs of their species or system. Practitioners interested in monitoring species occupancy should review additional concepts and occupancy model assumptions during the monitoring project design phase (MacKenzie *et al.*, 2017).

Defining the Area of Interest: The Area of Interest is the space over which monitoring practitioners hope to make inference, recognizing that only a subset of locations within the Area of Interest can likely be selected for monitoring and be surveyed. Virtually all biological monitoring programs lack the ability to census large areas, and there is a near-universal need for drawing inference about these large areas based on sampling a subset of locations within these areas (Yoccoz *et al.*, 2001). Defining the Area of Interest differs with different monitoring objectives. For example, the Area of Interest may be potential habitat(s) in the species' current or historical range or within geopolitical boundaries (*e.g.*, county park network, or state forest lands). MacKenzie *et al.* (2017) provide the following considerations for defining the Area of Interest: 1) Ensure the Area of Interest is consistent with monitoring objectives (objectives will outright define the Area of Interest, or help bound it), 2) Address logistical issues (site access or remoteness), and 3) Eliminate areas of 'non-habitat' (impervious surface cover, water bodies, etc.). Once the Area of Interest is defined, then practitioners must define additional key sampling terms, namely the Sampling Units and the Season (or time frame) over which the species is available for detection at occupied Units (Table 1). These definitions will help practitioners make decisions about sample size and sampling effort. Figure 3 provides an example of an Area of Interest for monitoring *B. affinis.*

Defining a Sample Unit: Sampling Unit is a general term used to represent a location or patch, located within the Area of Interest, where occupancy of the focal species will be evaluated (Table 1). Sampling Units are defined by practitioners developing a monitoring project and are informed by the monitoring objectives, species biology, and practical constraints such as logistics and cost. A Unit may be as small as a patch of flowers in a desert matrix or as large as forest stands. Units may vary in size (*e.g.*, farm fields, forest patches, city parks) or be uniform in size (grid cell, habitat plot, or transect). The area of each Sampling Unit must be reported to calculate sampling effort, a *core* data field for this framework. Yoccoz *et al.* (2001) defines all Units that exist within the Area of Interest as the Target Population, from which a subset of Sampling Units is selected for monitoring and data collection. Importantly, defining the Unit implies the spatial scale at which occupancy will be estimated from the resulting data. For example, the U.S. Forest Service may wish to understand how occupancy of a declining bee species is affected by forest clearcutting and subsequent forest regeneration. Here, the Sampling Units may be defined as a discrete number of timber stands, and the Target Population is all timber stands found within the Area of Interest, which may be all National Forest Lands owned by the U.S. Forest Service, across the known range of the species. Harvested stands could be stratified among

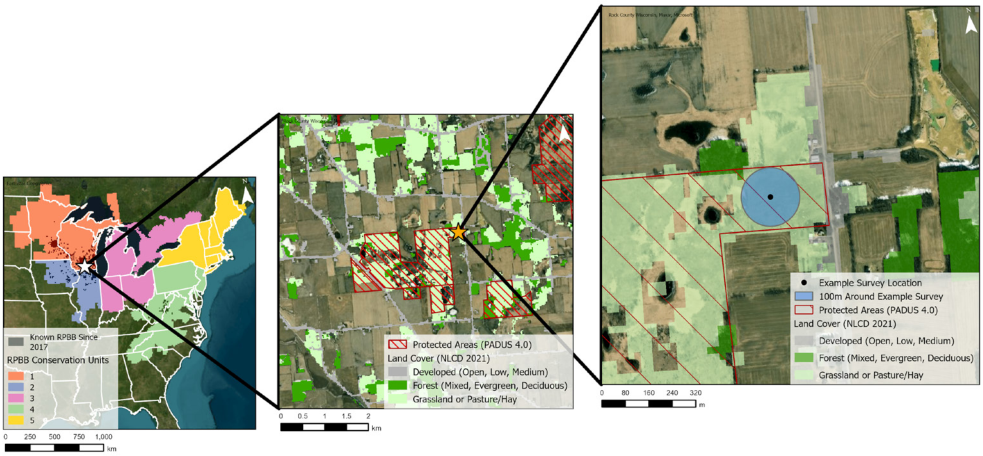

Figure 3. Defining the Area of Interest and Sampling Units for a monitoring effort for the federally endangered rusty patched bumble bee (*Bombus affinis* Cresson). The left figure shows the species' historic range, divided into five Conservation Units (USFWS, 2021). The Area of Interest for Objective 1 includes Conservation Units 1, 2, and 5, focusing on areas where *B. affinis* has been detected since 2017 (dark shade). The Area of Interest for Objective 2 will include all five Conservation Units. The center figure shows an example Sampling Unit consisting of grassland, forest, or developed land that is also public land. The right figure depicts a Sampling Unit, defined as a 3.14 ha circle (100-m radius) where Replicate Surveys will be conducted for *B. affinis*.

relevant focal age classes (*e.g.*, 1–3, 6–9, and 12–15 years post-harvest) and a stratified random sample of stands could be selected to ensure replication across a range of stand ages. Additionally, a subset of unharvested stands should be included as 'controls'.

Ideally, all of the Units within the Area of Interest (Williams *et al.*, 2002, Chapter 5) would be sampled, yet this is rarely achieved due to practical and logistical constraints. Instead, nearly all existing biological monitoring programs stress the need for probabilistic selection of Sampling Units to ensure that inferences drawn from the Units are representative of the Target Population. Non-probabilistic or ad hoc approaches to selecting Sampling Units (*i.e.*, selecting only the most florally diverse native prairies, sampling exclusively along roadsides or in cities because they are easily accessible) may be necessary in some cases, but practitioners should strive for probabilistic sampling whenever possible. If the Sampling Units are not representative of the Target Population, then insights gleaned from monitoring data are not applicable to the entire Area of Interest. Probabilistic sampling designs are important components of biological monitoring (Yoccoz *et al.*, 2001), and practitioners should develop a Unit selection process prior to initiation of monitoring. MacKenzie *et al.* (2017) provide examples of several probabilistic sampling schemes that can be used when monitoring occupancy. As with all other forms of biological monitoring, convenience sampling should be generally avoided as it does not represent a probabilistic sampling scheme. In addition, it is generally inadvisable to select Units based on knowledge of their likely occupancy state, such as Units that were known to be occupied in the recent past. Using prior knowledge of occupancy status to select Units typically does not result in a representative sample of the Target Population and has the potential to bias estimates of occupancy for the entire population (Fournier *et al.*, 2019). If there is interest in selecting Units where the focal species is known to occur, then practitioners must recognize that the estimated level of occupancy is likely to be higher than for a random sample of study Units throughout the Area of Interest. If practitioners have interest in Sampling Units where the species is known to occur, these Units should be treated as a different stratum. For example, our Case Study describing *B. affinis* monitoring includes Sampling Units selected across two strata: one where prior knowledge of occupancy was used to select Units and another stratum where no prior knowledge was used.

The number of Sampling Units selected for monitoring will be driven by monitoring objectives, species biology, Area of Interest, and time availability of monitoring practitioners. Although there is no general rule as to the minimum or optimal number of Sampling Units for estimating occupancy, we note that practitioners should expect to include tens or even hundreds of Sampling Units within their monitoring project. When estimating occupancy, we often sacrifice sampling depth (*e.g.*, detailed data collection at a few Units) for sampling breadth (*e.g.*, collecting a modicum of data across multiple Units). While sampling this many Units may seem daunting to individuals familiar with traditional bee sampling techniques, we note that collecting detection and non-detection data does not often require the level of effort required by other bee monitoring protocols (see Replicate Survey, below). Bailey *et al.* (2007) provide guidance on how to determine the appropriate number of Sampling Units to meet the desired objectives of an occupancy monitoring project, subject to economic and logistical constraints.

Defining the Season: Season is a term often used by ecologists to define a time period when the state variable (*e.g.*, occupancy, abundance, species richness) is assumed to be static or unchanged (Table 1). For occupancy, a Season should be a period when a Unit is either unoccupied by the focal species, or the Unit is occupied by the focal species and the species is available for detection (*i.e.,* Surveys have a greater than zero chance of detecting the species at occupied Units). Across multiple Seasons, occupancy status may change (*i.e.,* unoccupied Units may become occupied and occupied Units may become unoccupied), but within a Season the occupancy status is assumed static (*i.e.* occupancy state is assumed closed to changes). Often monitoring practitioners will be interested in understanding how the occupancy status changes across multiple Seasons and what environmental factors are driving the observed changes. A single year or growing season is often used as a starting point for defining a Season; however, species phenological information can be useful for honing the definition. For example, adult Mojave poppy bees (*Perdita meconis* Griswold; Andrenidae) are actively flying and available for detection during the brief bloom periods of their host plants, the prickly- and bear-poppies (Papaveraceae, *Argemone* sp. *and Arctemecon* sp.) (Chanprame *et al.*, 2024). Here, it may be appropriate to define a Season as a two-week period when the poppies are blooming and poppy bees are actively foraging, as opposed to other times in the year when they are in other life stages and nesting underground. Similar to defining a Sampling Unit, a Season is defined by practitioners developing a monitoring project and is informed by the monitoring objectives and species biology. Typically, a Season is defined as a period when the species is available for detection, which is often going to be when adult bees are actively flying and foraging. For example, our Case Study provided below on *B. affinis* monitoring has a 3-month Season from late June to early September, reflecting the active flight period of the focal species. Importantly, defining the Season implies the temporal scale at which occupancy will be estimated from the resulting data and the time periods between which occupancy status may change. Highly specialized survey methods and design considerations will need to be implemented if practitioners wish to make inference of bees during non-flight periods of the species' life cycle, such as the overwintering stage.

Defining a Survey and Replicate Surveys: A Survey is a single sampling event conducted at a Unit (Table 1). Replicate Surveys should be conducted during a defined Season, when the occupancy state of a Sampling Unit is static. Occupancy analysis is dependent on multiple, repeated Surveys. These Replicate Surveys will be used to estimate species detection probability, so that practitioners can disentangle false absences from true absence. Replicate Surveys are achieved by conducting Surveys during multiple points in time within a Season, by having multiple, independent observers, or even multiple, independent sampling protocols. It is important that practitioners define what constitutes a Replicate Survey and strive to maintain this definition for all sampled Units. Practitioners should seek to avoid situations where Replicate Surveys are conducted in an inconsistent manner, or where duration varies across Surveys (*e.g.*, some visual encounter surveys last 10 minutes where others last 60 minutes). Data generated during Replicate Surveys will be used to account for species' imperfect detection.

A Survey could include a visual encounter survey, netting, eDNA sampling, camera traps, trap nests (MacIvor & Packer, 2016), or any other method of detection. We recognize that most surveyors are likely to use some form of active, in-field survey and therefore provide guidance below that focuses primarily on active surveys. There is no universal rule dictating the number of Replicate Surveys that should be conducted at a Sampling Unit, but the general recommendation is a minimum of three Surveys during the defined Season (i.e., flight period of the focal species) when detection probability of the focal species is high (>0.5 per Survey; MacKenzie & Royle, 2005). Three Surveys should be considered a minimum and additional Surveys may be needed to understand factors contributing to variation in detection probability. If practitioners have interest in obtaining precise estimates of species detection probability, or in understanding factors that influence species detection, then the sampling design will often be weighted towards having multiple Replicate Surveys at fewer Sampling Units. This approach can be highly advantageous during the initial phase of monitoring and can help inform the design of longer-term occupancy monitoring (Boone *et al.* 2023 a,b; Otto *et al.,* 2023). Once the detection process is better understood, the sampling design can be altered to focus more on occupancy estimation, which typically involves sampling additional Units with fewer Replicate Surveys at each Sample Unit. MacKenzie *et al.* (2017) provide detailed guidance on design tradeoffs for balancing the number of Sampling Units versus the number of Replicate Surveys conducted at each Sampling Unit. Bailey *et al.* (2007) provide working examples of how to evaluate project design tradeoffs within an occupancy framework. Practitioners can use simulations and pilot data to evaluate whether a given design is sufficient for achieving the desired monitoring objectives.

Defining Criteria for Detection: Practitioners should also define what constitutes a Positive Detection of the focal species to avoid ambiguous detection/non-detection data. This may include collection of a physical specimen, a photographic voucher, or visual confirmation by well-trained observers. Given the difficulties of identifying most wild bee species without handling them, we recommend some form of physical or digital vouchering for Positive Detections. Note that photographic vouchers can be reliably used to identify some bee genera (*e.g.*, *Bombus*), but are less reliable for other genera. Ambiguous detections can be recorded but should not be considered Positive Detections during analysis of monitoring data.

STEP 4. SELECT FIELD SAMPLING METHODS

Once the key sampling terms have been defined and a probabilistic sampling scheme has been developed, the next step is selection of field sampling methods for the monitoring project (Fig. 1). Various sampling methods can be employed for the collection of detection and non-detection data of bees [*e.g.*, haphazard walks, passive traps, active netting on hosts, camera traps, environmental DNA (eDNA)]. Regardless of whether a single individual or several dozen individuals are detected within a single Survey, the Unit is occupied. Thus, occupancy Surveys can often be shorter durations relative to traditional abundance surveys where observers need time to collect multiple individuals. For all monitoring projects, details of the sampling protocol (*e.g.*, detection method, such as active netting) and sampling effort (*e.g.*, the Survey duration and the area of the Sampling Unit) are *core* data fields that must be reported (Rousseau *et al.*, 2024; Du Clos *et al.*, 2025). Whenever possible, sampling protocol and effort should be decided upon prior to data collection and standardized across Replicate Surveys (refer to Step 3: Monitoring Design). Regardless of the sampling method used, it is important to maintain associations between the detection and non-detection data by recording the *core* data fields: Sampling Unit name/ID, sampling location, date, time, observer name, duration of the Survey and Sampling Unit Area (Table 2). *Recommended* and *optional* data fields, and any other relevant information following *The Wild Bee Data Standard* (Du Clos *et al.,* 2025) can also be recorded to maintain the long-term viability of these data (Table 2).

Active Surveys: Active Surveys involve methods where one or more observers are actively engaged in looking for one or more focal species within a Sampling Unit (*e.g.*, haphazard walking, active netting on floral hosts). Active methods are highly advised, especially when the monitoring is limited to one or several focal species. Duration of active Surveys will vary widely based on factors such as monitoring objectives, project logistics, and the size of the Sampling Unit. In general, practitioners should ensure the Survey duration provides the field observers with a reasonable chance of detecting the focal species, assuming it is present and available for sampling within the Unit. Most active sampling protocols range from 10 to 60 min, but needs may vary depending on the biology of the focal species or the size of the Sampling Unit. We recommend standardizing Survey duration for all occupancy monitoring projects. Having Survey duration standardized (*e.g.*, defining a Survey as a 30-minute search) will make it easier to interpret Survey-specific estimate of detection probability. Shorter durations may serve to increase the number of Sampling Units that can be visited in a given time period but should not be so short that the focal species has an extremely low likelihood of being detected, when present. In the Case Study provided below, a Survey is a 30-minute period where a single observer is actively looking for *B. affinis* within the Sampling Unit at a time of day when the focal species is active.

Non-lethal: Non-lethal Active Surveys can be conducted for a limited number of bee species that are easily identified in the field or from photographic vouchers. Non-lethal methods with photographic vouchers may be required for protected species. In this case, at least one representative voucher of each species should be photographed. It is advisable to use established protocols for photographing bees, such as the protocol developed for the Xerces Society for Invertebrate Conservation's Bumble Bee

Table 2. *Core*, *recommended* and *optional* data fields to be recorded during Replicate Surveys following this occupancy monitoring framework and *The Wild Bee Data Standard* (Du Clos *et al.*, 2025). We note this is not an exhaustive list and practitioners will likely add/remove additional data fields based on the specific objectives of their monitoring effort. A full list of potential data fields (including many Sampling Unit covariates) is provided in *The Wild Bee Data Standard* (Du Clos *et al*., 2025).

Data Field	Level of requirement	Darwin Core Term(s)
Sampling unit location (Lat/Long)	Core	dwc:decimalLatitude, dwc:decimalLongitude
Sampling unit Name/Identifier	Core	dwc:fieldNumber
Survey date	Core	dwc:eventDate
Detection / Non-detection of focal species	Core	dwc:occurrenceStatus
Field observer name/Identifier	Core	dwc:recordedBy, dwc:identifiedBy
Survey start/End time	Core	dwc:eventTime
Survey duration	Core	dwc:samplingEffort
Area of sampling unit	Core	dwc:samplingEffort
Survey-specific covariates (e.g., weather)	Recommended	dwc:dynamicProperties
Habitat quality metrics	Recommended	dwc:habitat, dwc:eventRemarks
Geographically-specific stressors (*e.g.*, pesticide use)	Recommended	dwc:dynamicProperties
Floral host plant	Recommended	dwc:associatedTaxa
Non-target bee species detections	Optional	dwc:associatedOccurrences

Atlas projects (available at https://www.bumblebeeatlas.org/pages/survey-protocol). Note, however, that this protocol was developed and is very effective for bumble bees (Colgan *et al.,* 2024) but may not be appropriate for other bee groups. Indeed, some bee groups are difficult or impossible to identify to species even with extensive photographs. Appropriate species for field or photographic identification should be determined in advance of data collection by consultation with regional bee experts. During data collection, observers should indicate when voucher photographs are taken so that photographs can be linked with specific Sampling Units and Surveys. In practice, it is often beneficial to photograph a partially completed datasheet before and after a Survey so that any bee photos taken during a Survey can be easily cataloged. Photographic vouchers should be organized in a database and curated in a similar manner to specimen vouchers so that each photograph or set of photographs is permanently associated with detection data including the *core* data fields Sampling Unit name/ID, geographic location, and area; date, time, and duration of the Survey;

the *recommended* data field floral association, and any other relevant information following *The Wild Bee Data Standard* (Du Clos *et al.,* 2025).

Lethal: Active Surveys involving active lethal capture will be functionally similar to non-lethal methods, except that individual bees will be removed from the Sampling Unit and typically identified in the laboratory at a later date (refer to Levenson *et al*., 2025b in this issue for more information). Observers should keep detailed records of sampling events, effort, and methods following *The Wild Bee Data Standard* (Du Clos *et al*., 2025). For lethal collection, we advise euthanizing in a way that maintains tissue for molecular and parasite and pathogen analyses (refer to Strange *et al.,* 2025 and López-Uribe *et al.,* 2025 in this issue for more information). Lethal collection may not be authorized, or may require a permit, for some protected species (*e.g.*, state or federally Threatened or Endangered species).

Passive Surveys: Passive Surveys involve methods where devices are deployed within the Sampling Unit to collect detection and non-detection data. Bee bowls and vane traps are passive devices that are typically deployed for many hours or even days and are better suited for gathering species richness data (Portman *et al*., 2020; Levenson *et al*., 2025b). These Passive Surveys also require significant processing time for handling and identifying the multitude of bees collected, thereby negating the time savings compared to active detection/non-detection Surveys. In addition, Passive Surveys with long sampling windows make it more challenging to understand how factors such as time of day, weather, and local habitat quality influence species detection probability. Where the species of interest is especially difficult to detect with Active Surveys, or there are numerous species of interest that co-occur spatially and temporally, Passive Surveys may be a more appropriate method to employ.

Most of the Passive Surveys done when monitoring bees have involved lethal sampling (Droege *et al.,* 2016), but other biological monitoring efforts have successfully used non-lethal passive sampling for estimating occupancy of vertebrate wildlife (Strickland & Roberts, 2019; Kays *et al.,* 2020). Technological improvements with camera traps and eDNA methods will lead to increased adoption of these techniques into wild bee monitoring in the future. The deployment duration of Passive Surveys varies by method, with some, such as soapy water traps, being appropriate for shorter periods (24 h or less) and others, such as camera traps, being appropriate for long time periods. As with Active Surveys, practitioners should select a Survey duration that provides a reasonable chance of detecting the focal species, assuming it is present and available for sampling within the Unit and given the known limitations of the chosen method. Having a standardized definition of a Passive Survey is important for interpreting detection estimates when analyzing data within an occupancy framework. The number of trapping devices, arrangement, and duration should be held constant across all Surveys. For example, a Survey may consist of a trap line of 6 bee bowls, spaced 5 meters apart, activated for a 24-hour period.

Non-lethal: Non-lethal Passive Surveys are increasingly available with the development of machine-learning-based image processing for video and photographic devices and the development of molecular methods including environmental barcoding (Montero-Castaño *et al.,* 2022). The use of eDNA for detecting focal bee species seems to hold promise for bee monitoring in the future (Newton *et al.,* 2023), but most eDNA studies have yet to achieve species-specific resolution in bee identification, which limits current applicability to focal species monitoring. For some species, non-lethal passive traps may be effective, but additional research on camera traps and eDNA could help determine the benefits of widely integrating these tools into formal bee monitoring.

Lethal: Lethal Passive Surveys involve the deployment of one or more trapping devices such as bee bowls or vane traps that collect and kill target and non-target insects. Protocols for Lethal Passive Surveys are well established and often deployed for bees (Droege *et al.*, 2016; Packer & Darla-West, 2021). Given the history of Lethal Passive Surveys in bee monitoring, there are many existing data sets collected using these methods that could be used to provide historical estimates of species occupancy, which could be compared with estimates from more contemporary monitoring data. With passive lethal sampling, practitioners have flexibility in defining what constitutes a single Survey (Levenson *et al*., 2025b). For example, a Survey may be defined as a single bee bowl deployed at a Unit for a 6-h period, or an entire array of 30 bee bowls deployed over 24 hours. In many cases, Lethal Passive Surveys will not be necessary to examine occupancy of focal species. From the standpoint of estimating species occupancy and detection probabilities, a positive detection is confirmed when a single individual of the focal species is detected; detection of >1 individuals is not required, nor are counts of individuals easily incorporated into an occupancy analysis. Lethal collection may not be authorized, or may require a permit, for some protected species.

STEP 5. SELECT DATA FIELDS

Once monitoring objectives have been established, the state variables selected, the sampling scheme developed, and field sampling methods have been chosen, the last step in the monitoring project design framework is to decide what data to collect (Fig. 1). Du Clos *et al.* (2025) define *core*, *recommended*, and *optional* data fields to be recorded during data collection. For occupancy, we emphasize both *core* (*i.e.*, data required for achieving the stated objectives) and *recommended* (*i.e.*, nonessential data that are likely to provide additional benefit) data fields and provide brief examples of *optional* data fields. Table 2 provides a list of *core* data fields that are universal for any occupancy monitoring project. It is likely that other *core* data fields will need to be included, based on the objectives of each monitoring project. For example, if the objective of a monitoring project is to understand how the presence of the non-native honey bee (*Apis mellifera* Linnaeus) affects occupancy of a focal wild bee, then recording detection and non-detection data of honey bees would be a *core* data field "Non-target Bee Species Detections". For other monitoring projects, detections of *A. mellifera* may be merely *recommended, optional,* or omitted. Using monitoring objectives to guide data collection will ensure the most relevant data are collected and time is not wasted collecting extraneous information.

Data recording and reporting for this framework follows *The Wild Bee Data Standard* (Du Clos *et al*., 2025; this issue). *The Wild Bee Data Standard* uses Darwin Core (dwc) terms (Wieczorek *et al*., 2012) and describes their application to wild bee occurrence data (and associated ecological data) such as those collected through this framework. Darwin Core 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). Data recorded following *The Wild Bee Data Standard* will be suitable for publication on any of these platforms. To record data using this framework in alignment with *The Wild Bee Data Standard*, bee detection and non-detection data should be reported in **dwc:occurrenceStatus**. If bee counts were recorded, they should be reported in **dwc:individualCount**. *Core* site location information should be reported in **dwc:decimalLatitude**, **dwc:decimalLongitude**, and **dwc:FieldNumber**. If habitat type was recorded, it should be reported in **dwc:habitat**. *Core* sampling event information (*i.e.*, Survey time and date) should be reported in **dwc:eventTime** and **dwc:eventDate**. Practitioners should report the observer(s) and identifier(s) in **dwc:recordedBy** and **dwc:identifiedBy**, respectively. Any information specific to a Replicate Survey (*e.g.*, observer experience, site condition, method details) should be recorded in **dwc:eventRemarks**. Weather conditions for each Replicate Survey should be reported in **dwc:dynamicProperties**. Sampling effort, which includes the Survey duration and the area of the Sampling Unit, should be reported in **dwc:samplingEffort**. If photo vouchers are generated, their location should be reported in **dwc:associatedMedia.** For non-publicly held photo vouchers, please provide the name of the institution that manages the photograph database, or if photographic vouchers are shared online, please provide URLs where they can be accessed. When applicable, the flower a bee was observed on should be reported in **dwc:associatedTaxa**. Other bee species observed can be reported in **dwc:associatedOccurrences**. When these data are reported to an online data provider, all records should be recorded as human observations if non-lethally sampled or preserved specimens if lethally sampled in **dwc:basisOfRecord**. Lastly, this framework should be cited in **dwc:samplingProtocol** along with the specific methods employed (*i.e.*, active netting or passive sampling). Full details on using these Darwin Core terms are provided in *The Wild Bee Data Standard* and its associated templates (Du Clos *et al.,* 2024; 2025) and a summary table is provided in Table 2.

Covariates: Occupancy models allow incorporating covariates to account for variability in occupancy and detection and to test specific hypotheses related to monitoring objectives. Covariates may be collected both *in situ* and *ex situ*. Collecting environmental data at each Sampling Unit is important for understanding spatial patterns in occupancy and occupancy dynamics. For example, practitioners may choose to collect information on local habitat quality, land cover, or the prevalence of a biological threat, such as pesticides. Similarly, practitioners should consider collecting Survey-specific data associated with factors expected to influence detection of the focal species, such as observer experience, local weather in addition to time of day. Whether these data fields are *core* or *recommended* is largely determined by the objectives of the monitoring project. Furthermore, the spatial and temporal scale of covariate collection will largely be informed by monitoring objectives.

Guidance on incorporating and reporting these covariates is provided in *The Wild Bee Data Standard* (Du Clos *et al.,* 2025; terms: **dwc:dynamicProperties**, **dwc:eventRemarks**). Unmodeled variation (heterogeneity) in detection probability leads to biased occupancy estimates (MacKenzie *et al.,* 2017). Our Case Study below showcases specific detection and occupancy covariates that are collected during a Survey. *Ex situ* data, such as land cover characteristics, can also be collected via GIS before or after Surveys are complete. These data have the added benefit that they do not require time spent in the field that might be better spent visiting and collecting data at a greater number of Sampling Units.

CASE STUDY

Developing a Monitoring Project for the US Federally Endangered Rusty Patched Bumble Bee (*Bombus affinis*), Where Occupancy is the State Variable of Interest

The rusty patched bumble bee (*B. affinis,* Fig. 2) was listed as federally endangered under the U.S. Endangered Species Act in 2017 due to an estimated ~90% reduction in its distribution. Although the causes of *B. affinis* declines are not fully known, detrimental pathogens, small population genetics, habitat degradation, the effects of climate change (*e.g.*, prolonged drought), and pesticides may be responsible (Grixti *et al.*, 2009; Cameron *et al.*, 2011; USFWS, 2016). The current distribution of *B. affinis* is confined to just a few Midwestern and Mid-Atlantic states in the United States (USFWS, 2016; Hepner *et al.*, 2024). The *B. affinis* Recovery Plan developed by the U.S. Fish and Wildlife Service lists specific criteria for downlisting or delisting the species and it is understood that monitoring will play a primary role in evaluating progress towards recovery goals (USFWS, 2021). To consider downlisting the species from endangered to threatened, the Recovery Plan stipulates two criteria that must be met: 1) evidence of a minimum number of healthy populations and 2) a stable or increasing trend in occupancy over a minimum of five to ten years within each of the five Conservation Units identified in the recovery plan (USFWS, 2021).

One critical short-term need is to understand the factors associated with *B. affinis* detection, so that long-term monitoring efforts (>5years) can minimize false absences. Understanding species detectability will help optimize the monitoring design, which is especially important for efforts that operate on limited funding and volunteer-based effort.

We applied the framework (steps 1–5) discussed above to the design of a monitoring project for *B. affinis*, which was developed during a January 2024 *B. affinis* stakeholder meeting held in Bloomington, Minnesota. Participants (which included members of the U.S. National Native Bee Monitoring Network) agreed that a long-term monitoring project should estimate occupancy trends of *B. affinis* to inform the second downlisting recovery criteria in the *B. affini*s Recovery Plan (USFWS, 2021). Participants also discussed the need for monitoring to understand location-specific stressors and ecological information influencing *B. affinis* occupancy dynamics (*i.e.,* local colonization and extirpation that governs occupancy trends).

Step 1. Identify monitoring objectives: Objective 1 of this project, intended to be a short-term objective accomplished over one year of sampling, is to understand environmental factors that influence *B. affinis* detection. Knowledge gained from Objective 1 will help optimize long-term, larger-scale monitoring project associated with Objective 2. Objective 2 is aimed at estimating occupancy dynamics across the five Conservation Units and understanding location-specific stressors and environmental factors influencing *B. affinis* vital rates (*i.e.,* local colonization and extirpation). Objective 2 will also allow practitioners to estimate occupancy trends through time, allowing for direct evaluation of a recovery goal stated in the USFWS Recovery Plan (USFWS, 2021; Ellis *et al.,* 2025). Understanding *B. affinis* floral host plant use is also important for informing recovery efforts, so surveyors will also record flower visitation records while occupancy Surveys are being conducted.

Step 2. Define state variable(s) of interest: The state variable of interest for this monitoring project is occupancy.

Step 3. Design sampling scheme and define key sampling terms: The sampling scheme for Objective 1 is designed to understand factors influencing *B. affinis* detection. As such, Sampling Units will need to be in areas where the species is likely to occur. Accordingly, the Area of Interest during the first year of monitoring will be confined to the three Conservation Units (CUs) with known extant populations of *B. affinis* and further confined to areas that have been modeled by USFWS as having a high likelihood of extant *B. affinis*, with at least one known *B. affinis* detection since its listing in 2017 (Fig. 3). By selecting Sampling Units with a high likelihood of *B. affinis* occupancy, we know our occupancy estimates for Objective 1 will be biased high, relative to Units with no prior occupancy information. However, selecting Sampling Units with a high likelihood of occupancy is necessary for achieving Objective 1, so we can understand factors that influence *B. affinis* detectability.

Most Surveys will be conducted by volunteers, so Sampling Units predominantly occur on public lands, though private lands will also be incorporated when possible (Fig. 3). Adult *B. affinis* use a diversity of habitats, thus we define a Sampling Unit as a 3.14 ha patch (100-m radius circle) within a grassland, forest, roadside, or urban area within our Area of Interest (Fig. 3). Ideally, Sampling Units within this Area of Interest (public lands with known *B. affinis* detection since 2017) would be chosen in a probabilistic manner, stratified by number of known detections or annual frequency of detection (*i.e.,* number of years with detections since 2017). For practical purposes, the Units selected for Objective 1 will be an ad hoc sample (non-probabilistically drawn), selected on a voluntary basis, to ensure each Unit is surveyed multiple times within a Season. Sampling Unit selection will be modified for Objective 2, which we describe below. The Season for Objective 1 will correspond to a 3–4-month window (late June - early September) in a single year when *B. affinis* workers tend to be numerically abundant and actively flying. During this period, it is assumed the occupancy status of the sampled Units does not change (*i.e.,* occupied Units remain occupied and unoccupied Units remain unoccupied). This is a reasonable assumption given that by mid-June, *B. affinis* queens will have already established nests, so the locations of colonies are unlikely to change during this period. While occupancy is unlikely to change during the Season and is likely high based on our chosen Sampling Units, detectability is likely to change over Surveys (Boone *et al.* 2023a, b, Otto *et al.,* 2023); we aim to understand these changes in Objective 1. Following one year of data collection, analyses will be conducted to understand how *B. affinis* detection probability is influenced by time of day, day of year, local weather, and local habitat quality to achieve Objective 1 and inform future sampling for Objective 2. A Replicate Survey will consist of a 30-min non-lethal active visual encounter survey during daylight hours (between 900 and 1700), when *B. affinis* has a reasonable chance of actively foraging. We aim for a total of six replicate Surveys over the Season, though any Sampling Unit with at least two Surveys will be included in the subsequent analysis. A Positive Detection occurs when a single observer finds and vouchers a *B. affinis* worker, drone, or queen within the 30-min Survey. A photographic voucher is required to confirm a Positive Detection of *B. affinis* during a Survey. Physical voucher specimens of *B. affinis* are not allowed unless permitted to do so. Detection of other bumble bee species may be recorded and vouchered whenever possible but are not required.

The sampling scheme for Objective 2 expands on that of Objective 1. The Objective 2 sampling scheme includes all five Conservation Units, with each defined as a separate Area of Interest, as *B. affinis* downlisting criteria applies to each CU individually. Sampling Units within these Areas of Interest are defined identically to those for Objective 1: a 3.14 ha patch (100 m radius circle) within a grassland, forest, roadside, or urban area. However, for Objective 2, Sampling Units will be separated into two groups. One set of Sampling Units will be locations where *B. affinis* has been detected within the recent past (since its federal listing in 2017) and have a higher likelihood of being initially occupied. The second set consists of Units within the Areas of Interest that lack recent (2017–2024) *B. affinis* detections. Units within these groups will be selected probabilistically to achieve (1) ~66% historically occupied and ~33% historical unknown status units, and (2) spatially balanced coverage among the Areas of Interest. Selected Units that do not harbor flowers or have accessibility issues will be removed from the sampling pool. A Season for Objective 2 will correspond to a 3–4 month window (late June - early September) annually, but the duration of the Season may be adjusted based on findings from Objective 1. A Replicate Survey and Positive Detection are the same for Objectives 1 and 2. However, sampling schemes and key sampling terms are allowed to change based on what is learned from monitoring for Objective 1.

STEP 4. SELECT FIELD SAMPLING METHODS: A single observer will conduct a meandering walk within a Sampling Unit, actively searching for bumble bees on flowers, and record detection or non-detection information for *B. affinis*. Multiple observers can conduct simultaneous Surveys within a Sampling Unit, but the Surveys must be conducted independently (*i.e.,* no information shared between surveyors), and data records (detections and non-detections) kept separate for each observer. Surveys should not be conducted during rain events, during high wind (>20 kph), or temperatures < 15.5 °C. Survey-specific weather data will be collected at the onset of each Survey. Observers will wait at least one hour after rain subsides before conducting a Survey. Partially cloudy days or overcast conditions are permissible if observers can see their own shadow. *In situ* habitat data will be collected in the form of quantitative floral resource abundance and richness once per Sampling Unit, per Season. Protocols for collecting habitat data will be developed in the future.

STEP 5. SELECT DATA FIELDS: Objective 1 has several *core* and *recommended* data fields (Table 3). Upon the completion of sampling for Objective 1, *B. affinis* detection and non-detection data will be analyzed using a single-species, single-season occupancy model to determine how time of year, time of day, local weather, and local habitat quality affect *B. affinis* detection probability. Detection heterogeneity across different observers will also be explored. Results from Objective 1 will be used to evaluate design tradeoffs (Bailey *et al.*, 2007) and to refine survey protocols for Objective 2. Note that for *B. affinis*, data requirements deviate (*e.g.*, floral host is *core* data) from this framework, largely due to permit reporting requirements of this federally endangered species. An example of recorded data that describes a Survey for this monitoring project can be found in *The Wild Bee Data Standard* and its associated templates (Du Clos *et al.*, 2024; 2025).

Core and *recommended* data fields for Objective 2 will likely be similar to Objective 1 (Table 3), but these data fields are subject to change given what practitioners learn upon the completion of Objective 1. Results from Objective 1 will be used to determine which detection covariate information for explaining variation in detection probabilities are important for collecting to achieve Objective 2. One unique aspect of Objective 2 is the focus on estimating occupancy dynamics and understanding environmental stressors that are associated with these dynamics. There are myriad potential stressors impacting *B. affinis* occupancy dynamics, including detrimental pathogens, the effects of small population genetics, habitat degradation, pesticide use, competition, drought, and climate change. Table 3 provides coarse-level examples of

Table 3. Data fields for the *Bombus affinis* monitoring project. Each of the *core* or project-specific data fields should be collected and recorded during each 30-min Survey following the case study sampling scheme and *The Wild Bee Data Standard* (Du Clos *et al*., 2025).

Data Field	**Level of requirement**	**Darwin Core Term(s)**
Sampling unit location (Lat/Long)	Core	dwc:decimalLatitude, dwc:decimalLongitude
Sampling unit name/Identifier	Core	dwc:fieldNumber
Survey date	Core	dwc:eventDate
Detection / Non-detection of *B. affinis*	Core	dwc:occurrenceStatus
Field observer name/Identifier	Core	dwc:recordedBy, dwc:identifiedBy
Survey start/End time	Core	dwc:eventTime
Survey duration	Core	dwc:samplingEffort
Area of sampling unit	Core	dwc:samplingEffort
Survey-specific weather (wind, temp, humidity, cloud cover)	Core	dwc:dynamicProperties
Land cover covariates	Core	dwc:dynamicProperties
B. affinis floral host plant	Core	dwc:associatedTaxa
Habitat quality/Degradation & land cover metrics	Core	dwc:habitat
Pesticide treatments	Recommended	dwc:dynamicProperties
Bombus pathogen detection	Recommended	dwc:associatedOccurrences
Spatially-specific drought & climate indices	Recommended	dwc:dynamicProperties
Non-target *Bombus* species detections	Optional	dwc:associatedOccurrences
Floral host plants of non-target *Bombus*	Optional	dwc:associatedOccurrences

environmental threat data (*e.g.*, pesticides and pathogens) that could also be collected at each Sampling Unit, to understand their effects on *B. affinis* occupancy dynamics. For example, protocols for pathogen sampling could be adapted from Strange *et al*. (2025) and incorporated into this monitoring project. These threats are currently listed as *Recommended* data fields because they are important for understanding *B. affinis* occupancy dynamics; however, protocols for incorporating them into a monitoring design are currently unavailable. Although there is value in collecting data on all potential stressors, the monitoring project will primarily focus on the habitat quality affecting local colonization and extirpation rates. Specifically, data will be collected so that local colonization and extirpation rates can be modeled as a function of changes in floral resource diversity and abundance and changes in land cover through time. Floral resource data will be collected *in-situ* once per Season. Land cover will be quantified annually in a GIS at 250, 500, and 1000m from the Sampling Unit location, derived from the National Land Cover Database (https://www.mrlc.gov/data) and Cropscape - Cropland Data Layer (https://nassgeodata.gmu.edu/CropScape/). As the monitoring project matures, data collection on additional stressors (*e.g.*, pesticide use, pathogens, drought) will be added so that region-specific stressors can be investigated.

CONCLUSIONS

In this article, we provide a framework for focal species monitoring where occupancy is the state variable of interest. Establishing objectives is an important first step when developing a new biological monitoring project (Yoccoz *et al*., 2001); clearly defined objectives are critical for monitoring wild bees (Otto *et al*., 2025). Once monitoring objectives have been established, then practitioners can work with biologists and quantitative ecologists to design a sampling scheme, define key terms, select sampling methods, and determine *core* and *recommended* data fields.

Although there is a lot of interest in collecting bee data in the name of monitoring, we caution against a rush to data collection without first answering two questions: 1) *Why are we monitoring?* and 2) *What demographic properties are we monitoring?* Careful thinking during the initial phase of monitoring project development will ensure that years of field sampling will lead to desired outcomes and measurable gains of information. As demonstrated by more established vertebrate monitoring programs, occupancy has several inherent advantages for bee monitoring (Otto *et al*., 2025), and we hope this article provides practitioners with a useful framework for designing their own bee monitoring projects where occupancy is a state variable of interest.

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