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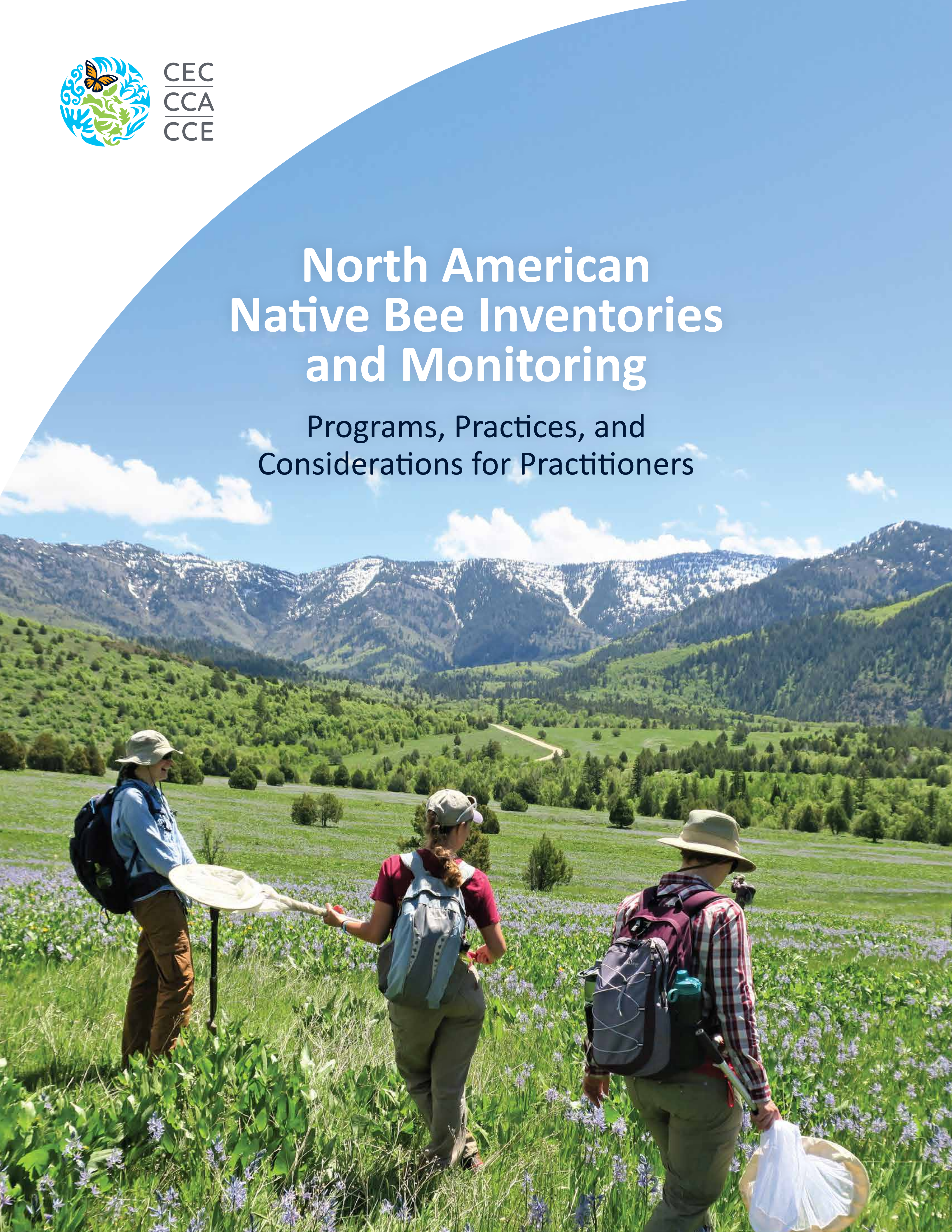
North American Native Bee Inventories and Monitoring

Programs, Practices, and Considerations for Practitioners



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List of Abbreviations and Acronyms

CEC	Commission for Environmental Cooperation
Conabio	*Comisión Nacional para el Conocimiento y Uso de la Biodiversidad* [National Commission for the Knowledge and Use of Biodiversity of Mexico]
Conanp	*Comisión Nacional de Áreas Naturales Protegidas* [National Commission of Protected Natural Areas of Mexico]
DNA	deoxyribonucleic acid
Ecosur	*El Colegio de la Frontera Sur*
eDNA	environmental DNA
eRNA	environmental RNA
GBIF	Global Biodiversity Information Facility
LiDAR	Light Detection and Ranging
NGO	nongovernmental organization
RCN	US National Native Bee Monitoring Research Coordination Network
RNA	ribonucleic acid
TDWG	Biodiversity Information Standards (Taxonomic Databases Working Group)
USDA	The US Department of Agriculture
USGS	The US Geological Survey
US NPS	The US National Park Service
VLR	vertical-looking radars

Abstract

Recognizing the increasing number of native bee-focused monitoring programs in North America and the need for baseline data, the Commission for Environmental Cooperation convened experts from Canada, Mexico and the United States in a May 2022 online workshop. This report presents a picture of the current state of native bee monitoring, inventories and surveys across the continent based on a questionnaire and associated literature search conducted following the virtual workshop, in mid to late 2022. Four primary monitoring methods are described (bowls/pans/cups, blue-vane traps, netting and photos). Broader program considerations are described as well, such as data management and standards, emerging technologies, and the involvement of non-experts. Case studies highlight a large native bee monitoring effort that has been initiated in the United States, the cultural value of native stingless bees in Mexico, and the power of community science in Canada to monitor native bees. The report concludes with recommendations drawn from both the workshop discussions and subsequent research.

Executive Summary

Monitoring native bees across broad spatial and temporal scales enables researchers to assess species' status, identify drivers change and focus conservation efforts. Native bee monitoring involves a multifaceted range of participants from various organizations, and often requires some degree of coordination to gather data and trends on species that transcend ecological and governmental borders.

In North America, native bee monitoring efforts have expanded in recent years to provide critical information to researchers, as required to understand and halt bee decline. Monitoring programs are fundamental to support evidence-based conservation efforts and maintain and enhance native bee communities and pollination services. It is clear that those involved in monitoring programs seek to increase data facilitation and sharing between groups with similar goals or species of concern. Amid the interactive effects of multiple drivers that impact native bees (habitat loss, land-use intensification, pathogens, parasites and climate change), practitioners and managers seek to establish baseline information against which change in species or communities can be accurately assessed. The Commission for Environmental Cooperation convened experts from Canada, Mexico, and the United States virtually in May 2022 to discuss the current state of monitoring and needs within native bee programs across the continent. Issues were raised, such as funding, accessibility to data on the species or ecosystems being monitored, access to taxonomic expertise, local and governmental support across various levels, and gaps in current knowledge.

Following the virtual workshop, a questionnaire was distributed to participants and their networks, and a literature review was conducted to provide an overall glimpse into the status of native bee monitoring in North America and identify future priorities to strengthen conservation efforts.

As native bee monitoring continues to evolve and expand, this report provides an understanding into the current status of existing North American programs, the structural characteristics new programs may take for future monitoring and considerations for decision-makers to take into account when faced with the possibility of enhancing monitoring capacity on any spaciotemporal scale. Some recommendations are offered, including:

- Enabling and empowering monitoring programs to have a voice in future conservation decisions.
- Implementing the necessary elements to sustain long-term monitoring in a way that facilitates information accessibility and sharing across national and international scales.
- Involving individuals from all possible sectors to expand monitoring capacity, while maintaining awareness that available taxonomic expertise is limited and always necessary for successful monitoring.
- Continuing to strengthen relationships and coordination efforts to enhance the results of monitoring, including aligning data standards.

Acknowledgments

A Steering Committee of federal agency representatives advised the CEC on this project, including Greg Mitchell, Environment and Climate Change Canada; Steve Javorek, Agriculture and Agri-Food Canada; Ryan Drum and James Weaver, US Fish and Wildlife Service; Esther Quintero, National Commission for the Knowledge and Use of Biodiversity (*Comisión Nacional para el Conocimiento y Uso de la Biodiversidad*—Conabio); Ignacio March, National Commission of Protected Natural Areas (*Comisión Nacional de Áreas Naturales Protegidas*—Conanp).

This project would not have been possible without the valuable information provided by the workshop participants and questionnaire respondents.

1 Introduction

This report presents a collection of example protocols, best practices, case studies, advice and considerations as part of the Commission for Environmental Cooperation (CEC) project "Advancing Pollinator Conservation throughout North America". This two-year CEC project focuses on three primary themes: 1) sharing native bee inventory and monitoring efforts occurring across Canada, Mexico and the United States, and identifying best practices; 2) developing decision support tools to guide trinational native bee inventory and monitoring efforts; and 3) developing communications materials to advance trinational native bee conservation. The first phase of this project included a virtual workshop held in May 2022 with experts from North America. The workshop and this compilation report seek to illuminate existing efforts across North America to monitor native bees and share strategies to help organize and mobilize a strategic, coordinated approach for inventory and monitoring efforts in North America.

This CEC activity began with a virtual workshop, held as two three-hour sessions in May 2022, convening more than 40 experts from government, academia and nongovernmental organizations (NGOs) from Canada, Mexico and the United States (see Appendix A for the workshop summary). A questionnaire was then distributed to workshop participants, as well as additional experts identified by participants.

> The CEC's focus on native bees is based on a recommendation from a February 2020 workshop held in Oaxaca, Mexico under the "Strengthening Regional Pollinator Conservation to Secure Local Benefits" project. For more information, see: <www.cec.org/category/ecosystems/monarch-and-pollinator-conservation>

Information in this report was collected from the virtual workshop held in May 2022, the online questionnaire, and a literature review. It is intended to serve as a reference for practitioners interested in seeking to establish or expand native bee inventory and monitoring efforts, or to identify opportunities for collaboration with similar or complementary programs underway in North America. This work is intended to support native bee inventory, monitoring and conservation efforts across Canada, Mexico, and the United States, but does not represent an overall framework or trilateral monitoring plan for native bees.

Section 2 of this report provides a snapshot of native bee inventories and monitoring in North America, based on the questionnaire responses. Section 3 discusses practical considerations regarding native bee inventory and monitoring program design and development, informed by questionnaire responses and a wider literature review. Section 4 presents some key take-aways about native bee inventories and monitoring in North America. Throughout, we also highlight a large native bee monitoring effort that has been initiated in the US, the cultural value of native stingless bees in Mexico and the power of community science in Canada to monitor native bees. These examples were chosen because they explore cross-cutting themes (e.g., using native bee monitoring to understand larger ecosystem changes) and example programs that highlight progress towards national and international coordination, the involvement of citizen scientists and a community-driven project.

2 Native Bee Inventories and Monitoring in North America

Many types of monitoring programs target the six families of native bees in North America (*Apidae*, *Megachilidae*, *Halictidae*, *Andrenidae*, *Colletidae* and *Melittidae*). There is currently no unified approach to monitoring native bees across the continent, and various approaches reflect the diversity of purposes, geographies, target species, technical expertise of participants, resources, as well as other factors. Capturing a comprehensive picture of native bee monitoring programs across North America is complicated by the hundreds of diverse stakeholders involved in these efforts, who are organized across communities, subnational regions, nationally and internationally in academia, community groups, nongovernmental organizations across various government agencies. Establishing a fully comprehensive account of native bee monitoring efforts across the continent is beyond the scope of this report.[1]

Sixty-five questionnaire responses describe native bee inventory and monitoring programs in Canada, Mexico and the United States. Respondents shared information about programs in all three countries, though there were many more submissions from the United States (52) than from Canada (9) or Mexico (8). This is likely a reflection of the number of actual programs in place, but also due to the active involvement of the US National Native Bee Monitoring Research Coordination Network (RCN) in questionnaire development and distribution.[2] While the responses do not provide an exhaustive list, they do illustrate the range of programs and commonly used approaches. This section provides some summary information from the questionnaire, but it is important also to acknowledge that counting "programs" is imperfect as they represent widely varied scales and intensity of monitoring effort.[3]

Appendix B provides a list of programs based on questionnaire responses. See also the workshop summary in Appendix A, which provides a status of native bee monitoring in each country based on workshop discussions.

2.1 Program overview

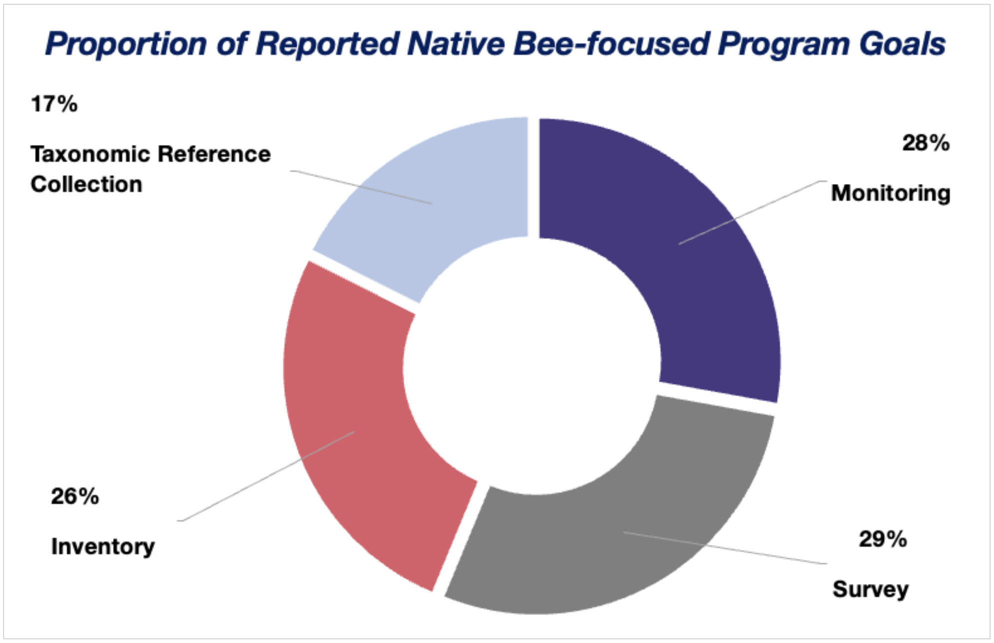
Questionnaire respondents described monitoring efforts, surveys, inventories and taxonomic reference collections as shown in Figure 1. Most respondents describe their program as having multiple goals across the options offered.

[1] The many efforts focusing on the non-native honeybee (*Apis mellifera*) were not considered for this report since this is not a native species. Additionally, some programs were counted more than once if they collect data in more than one country.

[2] For more information on this effort, see Woodard et al. 2020, and the case study on page 24 of this report.

[3] For the purpose of this section only, programs that identified themselves as collecting data in more than one country were counted in each country identified in their response to allow for national breakdowns.

Figure 1. Purpose of native bee-focused programs in North America, based on questionnaire responses



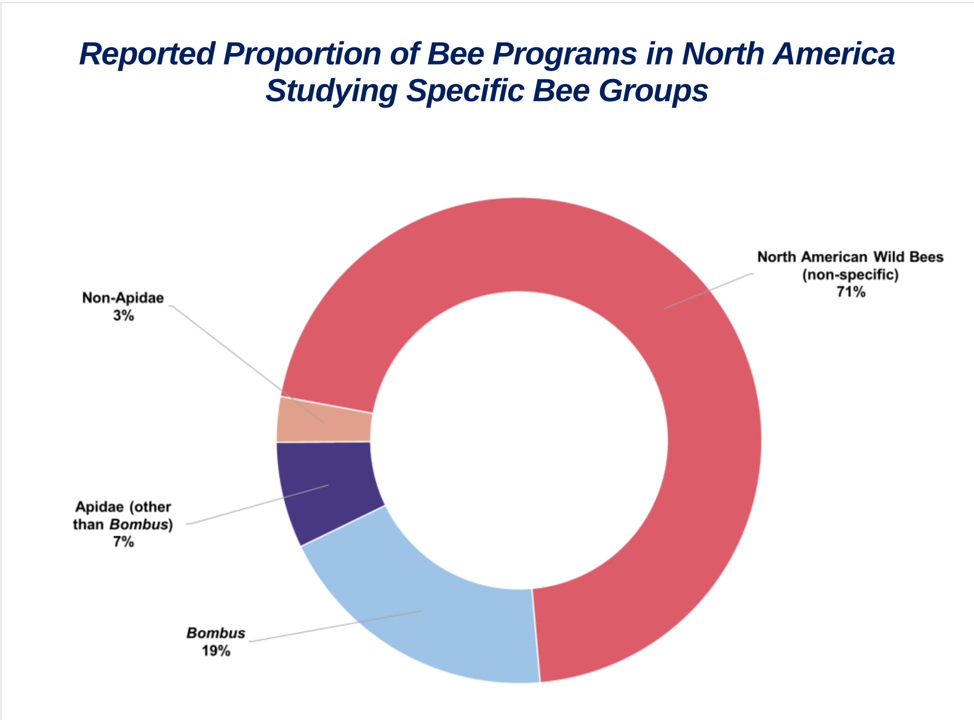
Note: Most programs were identified as serving more than one of the options offered.

Surveys: Report estimate of species' abundance and diversity in a fixed time and area
Inventory: Comprehensive list of bee species present in an area
Taxonomic Reference: Identification of bee specimens collected/detected in an area
Monitoring: repeated, systematic collection of data to detect long-term changes in the populations

Most programs reportedly do not target a single bee group but rather collect data on all bees that are captured. The types of bees more likely to be captured by traps are discussed in the sampling methods discussion in Section 3.1. Among programs that target a particular type of bee, a majority focus on bumblebees within the genus *Bombus* in the family Apidae, representing nearly one-fifth of all native bee monitoring programs.

Less than 10 percent of programs mention focusing on genera in the Apidae family other than *Bombus* (e.g., carpenter bees, orchid bees and stingless bees), or on bees outside the Apidae family (e.g., sweat bees, giant resin bees, wool carder bees, etc.). See Figure 2.

Figure 2. Genera or families targeted in native bee monitoring programs, based on questionnaire response

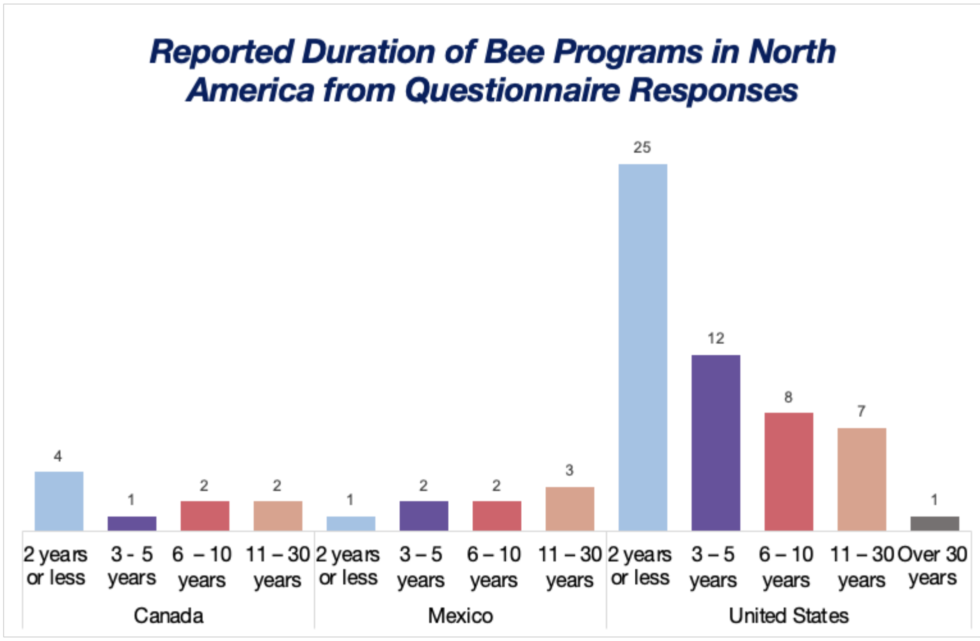


Notably, all the programs identified by survey participants in Canada either focus on *Bombus* or do not target a specific subset of native bees, whereas more than half of the programs in Mexico and the United States target non-*Bombus* species.

Native bee programs focus on the richness, abundance and community composition of pollinator species, often seeking to establish baseline information on native bee species within a particular area to understand the impacts on bees of landscape changes (associated with climate change, human activity, or otherwise), or the effectiveness of habitat restoration efforts. Some programs assess the population differences of a single bee species in multiple habitat types, in order to evaluate the effects of varying available resources or anthropogenic effects (i.e., habitat loss/fragmentation).

The longest-running native bee program in North America, captured in the questionnaire, originated in 1946 and is run by the US Department of Agriculture's (USDA) Agricultural Research Service, Pollinating Insect Research Unit in Logan, Utah. However, roughly half the responses from the United States reflect programs that began within the past two years. The duration of programs in Canada and Mexico is more evenly distributed, as shown in Figure 3. When considering duration, it is important to note that not all programs are intended to be sustained, and sustaining programs is not always possible due to funding and taxonomic expertise limitations.

Figure 3. Duration of native bee programs in each country based on questionnaire responses



2.2 Monitoring habitat

Not quite half (44 percent) of the programs described in the questionnaire responses take place in natural areas, sometimes in or adjacent to a protected area. Roughly one-quarter of the programs focus on either urban or agricultural habitats (28 and 23 percent respectively), while just five percent target other types of areas (restoration areas, an arboretum, industrial areas, etc.). See Figure 4.

Figure 4. Habitat types in which bee species are monitored in North America, based on questionnaire responses

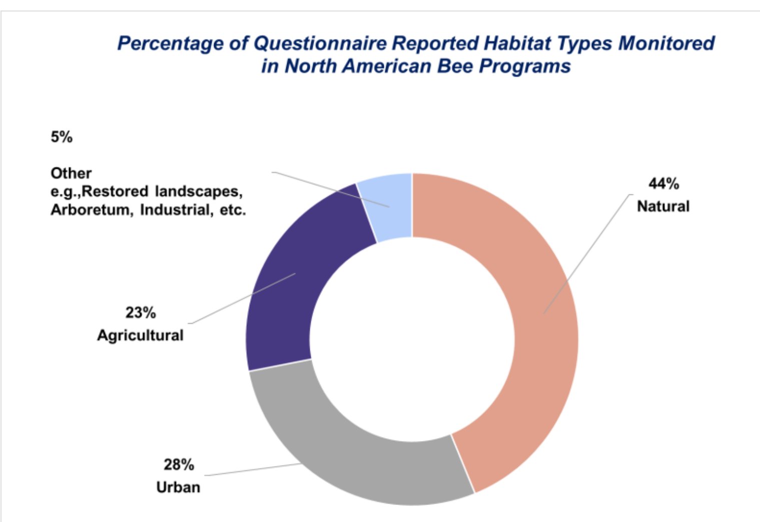
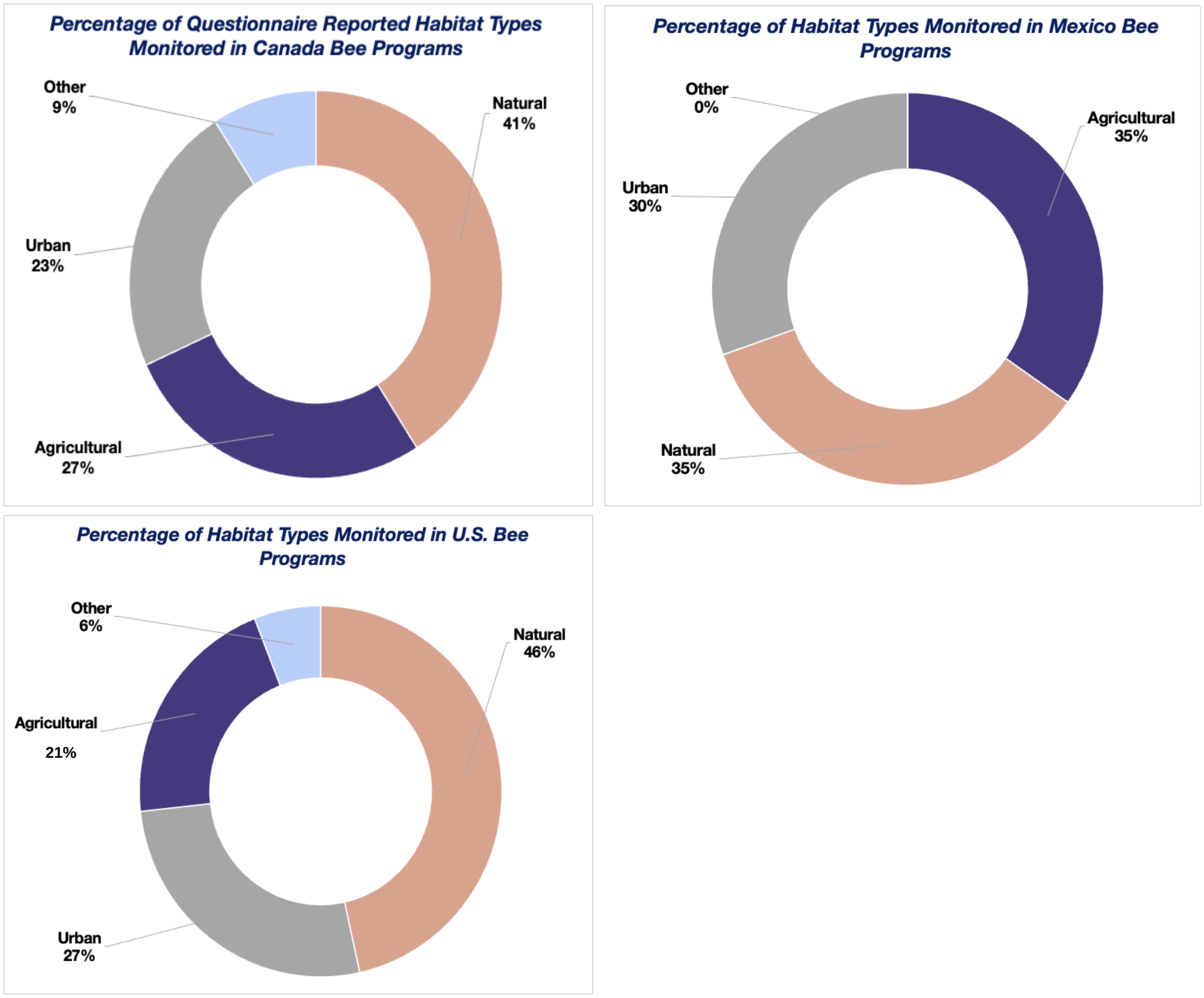


Figure 5. Percentage of habitat types monitored in Canada, Mexico, and the United States, based on questionnaire responses



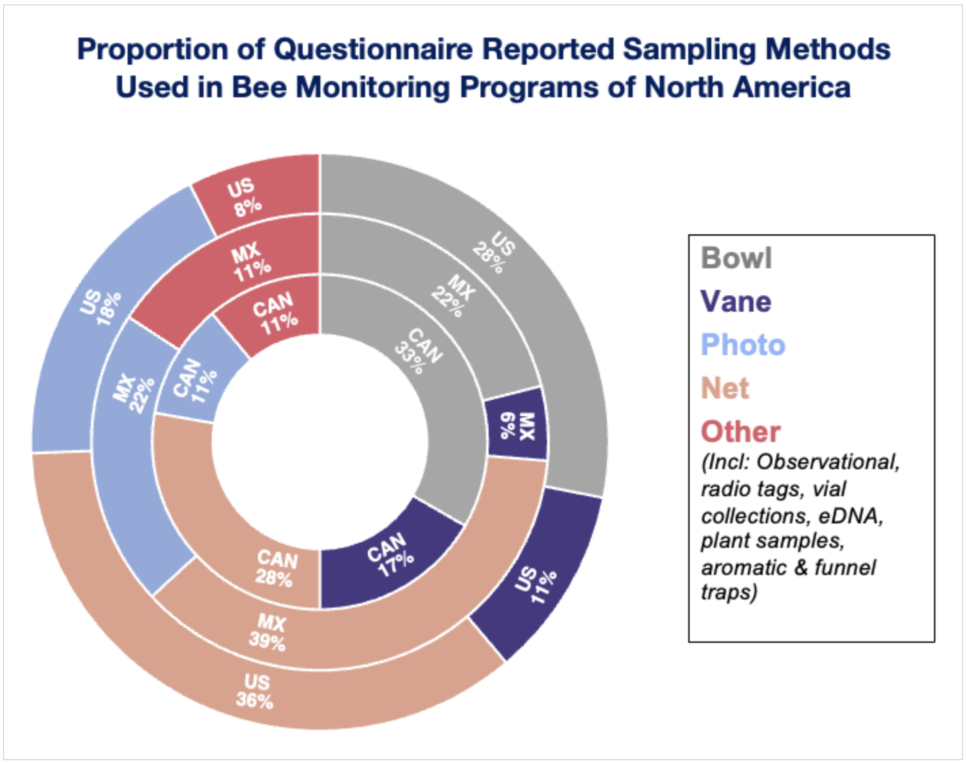
The breakdown of monitoring habitats in each country is roughly similar, though Mexico has a higher proportion of programs focused on agricultural areas than the other two countries, and the United States has a higher percentage focused on natural areas compared to Canada and Mexico. See Figure 5.

2.3 Native bee sampling methods

Figure 6 shows the sampling methods used in native bee programs across North America, according to the questionnaire responses, with bowls, vanes, nets and photos reported as the most common overall. Questionnaire responses also indicate that:

- Nets and bowls are the most common methods across the three countries, cited by more than half of the programs in each.
- All four of the most common methods are used in each of the generalized habitat types shown in Figure 5, although photos are relatively more common in urban areas than other areas.
- Sampling methods are very often combined, with bowls and nets as the most common combination.

Figure 6. Sampling methods used by programs in North America, by country, based on questionnaire responses



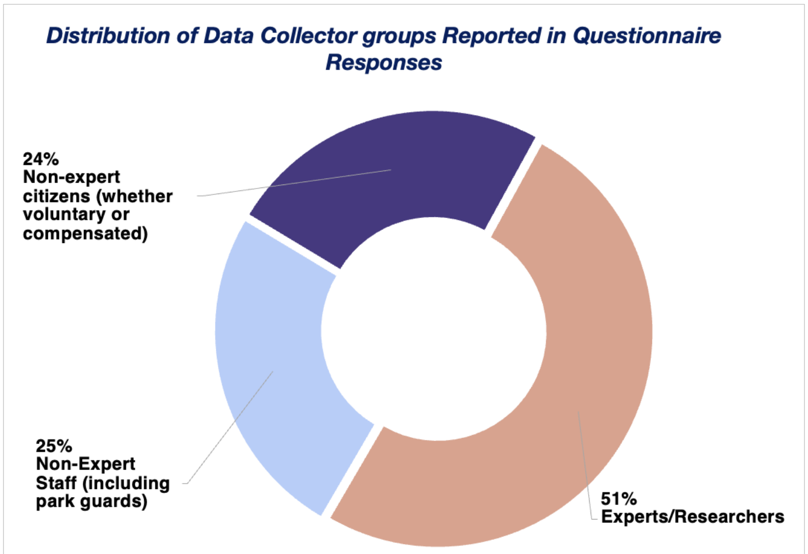
2.4 Program participants

Diverse participants are involved in native bee programs. As noted, programs are typically run by governments at different levels, universities, or nonprofit/nongovernmental organizations, frequently in partnership.

Many programs involve non-experts assisting with the collection of sampling data. Non-expert data collectors may be volunteer citizen scientists as well as employees who may not have scientific expertise but whose jobs take them to sampling areas. As shown in Figure 7, nearly half of the programs responding to the questionnaire indicated that non-experts (whether they be members of public or non-expert staff) are involved in data collection. The relative ease of different types of sampling methods are discussed in Section 3.2.

Taxonomic identification, on the other hand, requires a high degree of expertise. The broad diversity and often subtle microscopic characteristics necessary to identify native bee species generally requires extensive training and/or years of practice. In about three-quarters of the programs (based on the questionnaire responses), taxonomic identification is done by staff within a program, but it may also be done by a third party. In some cases, DNA barcoding is also utilized as resources allow.

Figure 7. Type of personnel involved in data collection based on questionnaire results

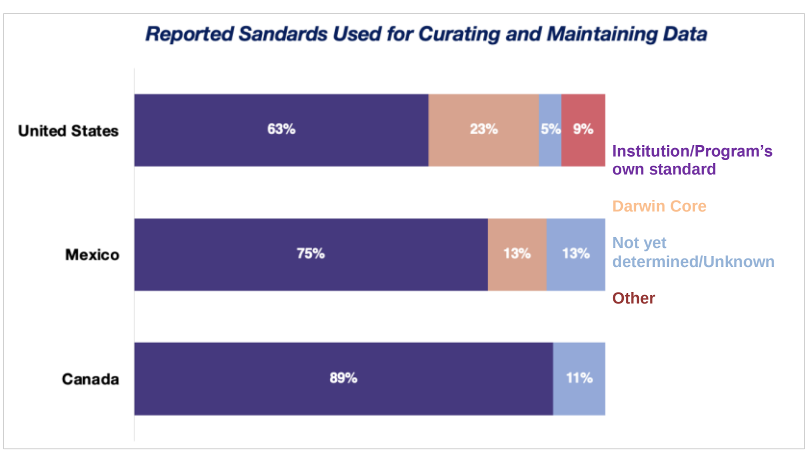


Note: Many programs involve both experts and non-experts

2.5 Data management

The majority of programs in each country use their own institutions' data standards, although this varies between countries, with 63 percent in the United States, 75 percent in Mexico, and 89 percent in Canada using institutional data standards. Questionnaire respondents that do not use their own institutional standard cited the Darwin Core Standard most frequently. Figure 8 summarizes responses from the questionnaire, but the topic is discussed further in Section 3.

Figure 8. Data standards used based on questionnaire responses



3 Program Design Considerations and Advice

This section provides considerations, advice and example programs and protocols related to the following elements of a native bee monitoring program: sampling method, spatial design, specimen repositories, monitoring of ecosystem functions along with bee attributes and data standards.

The purpose, context and resources available for an inventory or monitoring program will drive many of the decisions made about the program considerations listed above. For example, some programs are driven by conservation, while others may focus on bees' critical pollination services. Some programs focus on particular bee species or groups, while others seek to understand the diversity and abundance of pollinators more broadly. Some efforts are designed to gather baseline data whereas others work to understand population status and trends, biological community dynamics and/or the long-term effectiveness of conservation efforts. Programs may also have goals to educate and engage the public or non-experts, which will impact the sampling methods selected.

Some elements that are considered when defining the purpose of a native bee monitoring program include the species being studied, region of study, species-specific habitat associations, existing literature and data, conservation needs and climate change and anthropogenic impacts.

Creating a program to gather information on bees can have a single goal or multiple objectives, including the inventory, monitoring, surveying, or taxonomic reference collection of native bees. It is important to consider which objectives will fulfill the purpose of the monitoring program and the scale at which they need to be implemented. Due to the nature of funding sources and cycles, it may also be the case that a short- term program eventually becomes a longer- term program if resources are able to be sustained.

3.1 Sampling methods

There were four main sampling methods identified by questionnaire recipients for native bee inventory and monitoring programs in North America[4]: bee bowls (or pan traps; Figure 9), vane traps (Figure 10), nets (Figure 11) and photos/observations (Figure 12). This section provides an overview of the four main methods and some discussion of their advantages and disadvantages. See Tables 1–4. Regardless of the method, time spent sampling and/or person effort should be recorded.

[4] These four methods are the focus of this section because they emerged prominently in the online questionnaire conducted as part of this project. By contrast, Portman et al. (2020) describe just three methods (bowls, nets and observations) as common in the United States and Prendergast et al. (2020) does not consider observations but does include baits, vacuum/aspirators, malaise and trap nests.

Table 1. Overview of bowl/pan traps sampling method

Bowls (Pan Traps) ***Passive, lethal***	
Components	Colored bowls filled ¼ to ¾ with water and unscented soap (colors may vary across programs but typically include a combination of bright white, blue and/or yellow and may have an asterisk pattern drawn inside).
Placement	Along transect lines, usually with the placement of single bowls of alternating colors, or groups with one of each color.
Timing	24 to 72 hours Exceeding 72 hours of sampling can lead to the degradation of the specimen in the soapy water (Fulkerson et al. 2022, 12).
Specimen identification	Specimens may be sent off-site for identification or identified onsite by individuals with taxonomic expertise. Samples could also be sent off for DNA barcoding.
Other	Vegetation around the bowl/pan trap may be cleared or bowls may be elevated above vegetation cover to make it easier for them to be seen (Evans et al. 2018, 163; Galpern 2020, Survey Response). The Alaska Bee Atlas suggests that for microhabitats a sample size of 15 bowls is sufficient to accurately estimate species' abundance and diversity. Up to 30 bee bowls may be used for larger habitats; however, the sample size is dependent on the habitat to be studied (Fulkerson et al. 2022, 12). Minimize population impacts by avoiding use during queen bee emergence and foraging in early spring for non-solitary species (Droege et al. 2017, 2).

Figure 9. Bee bowl

Photograph by J. Crowder (2019). Retrieved from Flickr.

Table 2. Overview of vane trap sampling method

Vane Traps ***Passive, lethal***	
Components	Plastic jar with a cap in the shape of an upside-down funnel; typically, bright blue is used to attract the highest number and diversity of bees (Acharya et al. 2022, 1). Fumigant in traps kills the bees and other insects that may enter (Fulkerson et al. 2021, 13). The trap is attached to a stake to elevate it above vegetation.
Placement	Place at the end of transects in a sampling area when bee bowls are being used as a complemental method. Can be deployed as a singular method.
Timing	Traps are generally recommended to be left in place for 24 to 72 hours, though one protocol states that traps can be left in the sample area for up to seven days (Fulkerson et al. 2022, 14).
Specimen identification	Specimens may be sent off-site for identification or identified on-site by individuals with taxonomic expertise. Samples could also be sent for DNA barcoding.
Other	Traps should be elevated to about one meter and secured on the side to minimize water accumulation. Vane traps require slightly higher levels of time commitment than bee bowls, due to the possibility of some specimens not being killed after being trapped. Any bees that are still alive after the trap is collected must be transferred to a kill jar. Kill jars are sealable and contain a layer of plaster at the bottom which absorbs a killing agent, such as ethyl acetate (Fulkerson et al. 2022, 16). Minimize population impacts by avoiding use during queen bee emergence and foraging in early spring for non-solitary species (Droege et al. 2017, 2).

Figure 10. Bee trap

Photograph by S. Galbraith (2019). Retrieved from Flickr.

Table 3. Overview of net capture sampling method

Net Capture ***Active, can be lethal or non-lethal***	
Components	Bees are caught in a hand net; either specifically targeted or caught by sweeping through vegetation in a consistent pattern. Two techniques are used to capture bees: quick swings of the net or slowly placing the net over the flower and pinching the net closed (Fulkerson et al. 2022, 15).
Placement	Transects and areas vary; participants should not remain in one place for any extended period of time, but constantly walk around the sample site (Evans et al. 2018, 163). Walk at a pace of approximately 10 feet per minute (Jordan et al. 2016, 9).
Timing	Actual duration of sampling will vary but is likely limited by availability of data collectors.
Specimen identification	Depends in part on whether done as lethal or non-lethal method; if lethal, specimen may be sent off-site for identification. Non-lethal sampling involves transferring specimen to a vial after capture and placing it into an ice cooler to induce a hypothermic state (Hatfield et al. 2020, 10). The bee can be removed from the vial and photographed after 10 to 15 minutes, or until the bee's movement is slowed (Fulkerson et al. 2022, 17).
Other	A team approach can facilitate capture, timing the active search and recording data. If multiple participants are sampling a single area, the time spent actively sampling bees should be split equally between each person (Fulkerson et al. 2022, 15; Hatfield et al. 2020, 10). Focus on training people to identify bees based on movement, not simply size, shape, or color (Little n.d., 4).

Figure 11. Catching bees with nets

Photograph by R. Lehman (2018), Intermountain Forest Service, USDA Region 4. Retrieved from Wikimedia Commons.

Table 4. Overview of photo sampling method

Photo ***Active, non-lethal***	
Components	Bees may be photographed as they move from flower to flower, caught in a net and subsequently frozen, or transferred to a photo chamber until adequate photographs are taken of the physical features that identify species (Fulkerson et al. 2022, 16).
Placement	Variable
Timing	Variable
Specimen identification	May be done by off-site experts, but highly dependent on quality of photograph(s) taken.
Other	Ensure photographer's shadow remains behind them for the duration of the sample period (stand or approach facing the sun). Overshadowing a flower or quickly approaching a specimen can startle and cause them to flee, significantly lowering the possibility sufficient photographs will be taken to be able to identify the bee (Jordan et al. 2016, 39). Photos of bees on flowers are useful for recording the pollinator–plant associations and how many visitors are found at each type of flower. However, where possible this should always be paired with flower availability data so that over and underutilization can be determined. It is not recommended that solitary bees are only photographed, due to the difficulty of identifying important features by photographs alone, but instead surveyed using kill methods (Fulkerson et al. 2022, 17).

Figure 12. Photo observation of Common Eastern Bumble Bee

Photograph by R. Hodnett (2018). Retrieved from Wikimedia Commons.

3.2 Advantages and disadvantages of main sampling methods

Table 5 displays a summary of these methods and some of the merits and disadvantages of each. As discussed in Section 2, many programs use a combination of at least two or more of these methods.

Table 5. Summary of four main types of native bee sampling methods described in this report

Sampling method	Advantages	Disadvantages
Bowls/pan traps	• easy to deploy with limited training • inexpensive compared to other methods with respect to collecting the sample, but not necessarily specimen identification • easy to standardize (materials, protocol) • can include data collection of habitat, phenology, or geographical data (Hatfield et al. 2020, 12)	• will not attract all types of bees equally, therefore can preference certain species; may result in gender bias (sweat bees most often caught; Portman et al. 2020, 338) • color may impact trap's effectiveness and type of bees collected • cannot match bee to host flower • specimens may degrade • lethal, including bycatch • identification may require taxonomist
Vane traps	• easy to use and sustain (though requires more skill than bee bowls) • easy to standardize (materials, protocol) • can include data collection of habitat, phenology, or geographical data (Hatfield et al. 2020, 12)	• color may impact effectiveness and type of bees collected • cannot match bee to host flower • specimens may degrade • lethal, including bycatch • vane traps are slightly more costly to set up/make relative to bowls • identification may require taxonomist
Nets (sweep or target)	• able to target certain bees if collector is trained to recognize • can match bees with host flower, if desired • specimens collected in good condition and may be released • may be done non-lethally, so suitable for threatened species	• biased towards bees that are easier to see/catch, e.g., bumblebees • requires more skill than passive traps (bowls, vanes) • difficult to standardize, especially over uneven or wooded terrain (Krahner et al. 2021, 2) • relatively labor intensive and harder to sustain

Photos / Observations	• non-lethal and no bycatch, so suitable for threatened species (MacPhail et al. 2019, 2) • can serve as a scoping tool to determine suitable areas for formal observations (Cairns et al. 2005, 687) • can include data collection of habitat and plant associations, phenology, or geographical data (Hatfield et al. 2020, 12) • can be integrated with computer learning for identification purposes (see emerging methods)	• no specimen collected for further examination • difficulty in taking high quality photos suitable for species identification

Source: General considerations for bowls/pans, vane traps and nets are drawn from Prendergast et al. (2020) unless otherwise cited.

Considerations regarding bowls/pan traps

The merits of different sampling methods, though very briefly summarized in the table above, are more robustly debated in the literature. Trondstad et al. (2022) compared bowls/pan traps, vane traps and target netting for understanding changes in the abundance and richness of bees across diverse habitats and elevations in Wyoming (United States), concluding that vane traps caught more bees and a greater diversity of bees than bowl/pan traps, and required fewer samples than target netting (which targeted only bumblebees in this study). They recommended spacing vane traps 15 to 20 meters apart to monitor bees and bumblebees, and supplement bumblebee efforts with target netting when possible (Tronstad et al 2022, 3). The article also describes the power analysis used to estimate abundance and richness with as few traps as possible, but notes that sampling will need to be scaled up for monitoring in larger areas. The use of bowl/pan traps is also encouraged for areas where hand netting is unsafe or particularly difficult to implement consistently due to steep or otherwise challenging terrain (Krahner et al. 2021 emphasizes this in a study of monitoring options for steep vineyards in which bowl/pan traps are found to be more effective than the less commonly used malaise or trap nests).

Portman et al. (2020) calls bowls/pan traps into question, however, making clear that the emphasis on bowls/traps in the article is because they are so commonly used.[5] The primary problem with bowl/pan traps, according to the article, is that they tend to catch mostly *Halictidae* (sweat bees). This was determined based on a review of studies from diverse habitats, in which *Halictidae* comprised anywhere from 40 to 96 percent of bees captured. The only exceptions were during blooming time in apple orchards and in the Utah desert, settings which had very diverse bees present. While most bees in this family are easy to identify, some are not, and can thus require a high level of taxonomic expertise. The *Halictidae* bee family is also generally described as being of less conservation importance compared to others since it is known to be

[5] This finding, based on search of scientific papers, is supported by the results of the online questionnaire, in which bee bowls were shown to be the second most common sampling method after nets.

found in disturbed habitats (parking lots, dumps and gas station parking lots are given as examples).

While Portman et al. (2020) focuses on bowls/pan traps, it also states that the same concerns would exist for vane traps, including taxonomic bias and the uncertain relationship to floral cover (e.g., are bees more attracted to traps when there are no flowers present, or are bees more likely to be present during flowering and so more likely be trapped?). One of the studies cited in this review also raised the concern that vane traps could wipe out local populations of some species (Gibbs et al. 2017, 579). Additional questions about the value of bowls/pan traps include whether or not there is a bias between males and females (regarding which color bowl they may be attracted to), uncertainty about the relationship between bowl color and surrounding flowers (and whether some bees may avoid bowls out of preference for flowers generally) (Cane et al. 2000, 229).

Consideration of lethal sampling methods

Lethal methods are not recommended if a species at risk may be caught, or during the early spring when queens are flying and foraging before their first brood hatch (MacPhail et al. 2019, 599). (Not all bee species have queens, but bumblebees do and are commonly monitored species; e.g., the American Bumblebee.) At the same time, lethal methods bring the advantage that bees can be collected, stored and later identified by taxonomists (Freire-Ramírez et al. 2014, 510). Lethal methods also provide an opportunity to support taxonomy overall, as well as to study genetics and health by further examination of a specimen (Droege et al. 2017, 3).

A proposal for a national framework protocol for monitoring bees in the United States addresses considerations regarding the use of lethal sampling methods, citing the ease of use and replicability of lethal traps as having significant benefits towards establishing standardized baselines and trends over time (Droege et al. 2017, 3).

Droege et al. (2017) also explain that, in most cases, lethal sampling does not cause unnecessary deaths in a population. This is supported by Gezon et al. (2015), which found that sampling every two weeks with bowls/pan taps did not impact bee community structure. The review by Gibbs et al. (2017) compares vane traps to netting in blossoming orchards and finds that the vane traps added to the understanding of diversity in the study areas because they captured species[6] that were not seen in netting; however, they raise concerns that some species[7] declined over the three years studied and urge that vane traps be used with great caution.

[6] *Eucera atriventris*, *Eucera hamata*, *Bombus fervidus* and *Agapostemon virescens*

[7] *Lasioglossum pilosum* and *Eucera* spp.

Combining multiple sampling methods

Two (or sometimes more) sampling methods are often used together in a single program, frequently combining methods that are not time-intensive, such as bowls/pan traps and vanes, with those that are more time-intensive, such as netting or photos (Tronstad et al. 2020, 1).

Although resource intensive, active net capture on its own allows for the collection of a greater biodiversity of bees, as not all species are attracted to stationary traps (Domínguez-Álvarez et al. 2009, 430; Fulkerson et al. 2022, 15). Programs in the questionnaire that reported a single monitoring method were most likely to use net capture.

Involvement of citizen scientists

As noted in Section 2, it is common for native bee monitoring programs to involve the public ("citizen scientists") or other non-experts (such as park employees). Citizen scientists, in particular, may be involved in programs using iNaturalist to map and share observations or implementing simple sampling method such as bowl/pan traps. The benefit of citizen science participation is the increased scope of sampling that can occur in time and space. However, citizen scientists will often require some training and taxonomists may need to be involved to make initial IDs or verify IDs for bees, especially if the goal is to accurately document specimens at the species level.

Harnessing the power of citizen scientists: Bumble Bee Watch

Citizen science can benefit monitoring activities by improving coverage, reducing costs and providing benefits for participants; however, potential inaccuracies and errors can influence the interpretation of results (MacPhail et al. 2020b, 2). Having experts verify citizen science activities and findings is important to help ensure the efforts provide accurate and reliable information. *Bombus* species may be particularly good candidates for citizen science monitoring programs because they are charismatic and relatively easy to verify the species from good quality photos (MacPhail et al. 2020b, 4; Lye et al. 2012, 698; Suzuki-Ohno et al. 2017, 1; Falk et al. 2019, 13). Furthermore, 28 percent of North American bumblebee species are facing some degree of extinction risk (The Xerces Society n.d., IUCN Red List), therefore warranting monitoring and conservation.

"Bumble Bee Watch is a web-based citizen science program where participants photograph *Bombus* species anywhere in North America, upload photos and relevant site information and work through an interactive identification key" to name the species, which experts then verify (MacPhail et al. 2019, 599). The program is a cooperation between Wildlife Preservation Canada, the Xerces Society for Invertebrate Conservation, and the Faculty of Environmental Studies at York University, with founding partners and scientific advisors from the University of Ottawa, the Montreal Insectarium, the Natural History Museum, London, and BeeSpotter (University of Illinois). The program launched a website in 2014 and developed apps for mobile devices (MacPhail et al. 2019, 599). Users are not required to have skills in species' identification, and photographic sampling is non-lethal, negating the need for curation, equipment and monitoring protocols (MacPhail et al 2020b, 4). As of January 2018, 86 percent of all bumblebee observations submitted and verified had been identified to species level (MacPhail et al. 2019, 598). The Xerces Society is currently translating the website into Spanish to facilitate Spanish speakers' observations and involvement (questionnaire response).

Data from Bumble Bee Watch has been combined with other data sources to assess the status of the American bumblebee (*Bombus pensylvanicus*), leading MacPhail et al. to recommend a Critically Endangered status in Canada, using IUCN Red List criteria. This was the first study to combine citizen science data with expert-collected and historic data to examine the status of a bumblebee species in the country. Recent sightings were further compared to Google Maps and Street View to deduce preferred habitats, with the majority (73 percent) of recent sightings occurring close to grasslands and old fields (MacPhail et al. 2019, 607). Despite its recent establishment, Bumble Bee Watch data were reported to be "particularly valuable by researchers, as they represented 20 percent of recent records and 36 percent of recent location data" for this species (MacPhail et al. 2019, 605).

Bumble Bee Watch submissions were later examined to assess accuracy of species identification (MacPhail et al. 2020b; 1). On average, users were able to identify the species correctly about 53 percent of the time, which is similar to metrics in other programs (MacPhail et al. 2020b; 19). Users reported the species incorrectly 38 percent of the time and an additional nine percent of submissions were not bumblebees (MacPhail et al. 2020b, 10–12). However, accuracy varied by species. Only 10 species met the threshold of 80 percent agreement that would reduce the need for expert review, while the other 32 species fell below the threshold (MacPhail et al. 2020b, 19–20). Endangered species were more likely to be misidentified (MacPhail et al. 2020b, 20). This underscores the need for citizen science programs to undergo quality assurance protocols. Experts also identified that new educational materials and additional prompts or checkpoints in the submission process could help improve species' identification (MacPhail et al. 2020b, 25).

For more information on Bumble Bee Watch contact bumblebeewatch@xerces.org.

3.3 Spatial design

Spatial design is influenced by the purpose and objectives of a monitoring program. Most programs described in the questionnaire responses use stratified or opportunistic sampling (see Table 6), however, these designs can be combined with random sampling to supplement efforts to allow for more robust statistical inference.

Except for three bumblebee-focused programs that use a stratified design, the programs with this approach in the questionnaire responses are not focused on a specific species group. By contrast, questionnaire results indicate that the programs using an opportunistic design are specifically monitoring one or more bee families (or *Bombus*). For example, one monitoring program in Pinnacles National Park, California, used a previously established trail network in the park to collect and inventory native bee communities. Conducted from 1996 to 1999, this collection was the first time that inventory efforts took place in the region, and monitoring is still ongoing. The trails increased initial monitoring capacity, making it easier for participants to deploy collection methods (Meiners et al. 2019, 7). Another example of an opportunistic design is a study of pollinator plants at large-scale solar installations, where researchers used opportunistic monitoring to evaluate species composition in habitats with multiple orientations. Through monitoring the abundance and diversity of native bees, among other pollinators, it was found that planting essential pollinator plants improved their population levels at these sites (Dolezal and Caldwell 2021).

Table 6. Stratified and opportunistic spatial designs used in native bee monitoring programs

Spatial design	Description	Considerations
Stratified	Landscape is divided into smaller, equally sized areas, based on representative land-cover classes and each area is individually sampled.	Used to focus on priority areas, when the area being monitored is significant in size, or when habitats are heterogenous across a sample site or landscape (Hatfield et al. 2020, 9). Can allow researchers to obtain data that represent the entire population of multiple species.
Opportunistic	Sampling locations are largely based on ease of access *or* choices by the individual collecting the data (e.g., a person taking a photo with iNaturalist or monitoring along a trail network).	Can be used in heterogenous habitat, habitats with multiple species present, or when a habitat presents an opportunity to monitor a particular area. If enough people are conducting opportunistic sampling and there is some measure of effort (e.g., time spent sampling), then it is possible to derive robust population distribution maps and trends, e.g., eBird.

3.4 Archive and collections

Species archives and collections for native bees exist in North America, where programs can send their specimens for identification, processing and storage. Roughly half of programs in the survey responses store samples to collections in North America. A few of these key programs were highlighted in the questionnaire responses, including the US National Pollinating Insect Collection (the USDA Native Bee Lab) in Logan, Utah; Beneficial Insects Surveillance Network in Alberta, Canada; Colección Abejas de El Colegio de la Frontera Sur (Ecosur); and University of California at Santa Cruz and Santa Barbara.

Another type of collection to be acknowledged are photo archives, which are used as a tool for programs that utilize photography as a method for identifying specimen. The Bumble Bee Watch, USGS Bee Inventory and Monitoring and iNaturalist are examples of platforms where participants can submit photographs to be verified by experts.

3.5 Monitoring habitat, ecosystem functions and other parameters

The health of native bee species in North America is heavily dependent on the health of the surrounding ecosystem, flowering plant/species interactions, abiotic factors and the presence of predators, competition and diseases (Gezon et al. 2015). Pollination was listed by 22 of the survey responses as an ecosystem function being monitored in their program, and competition was also monitored by three of these programs. Prioritizing not only the monitoring of native populations, but also the associated plant species and influential environmental factors, can significantly improve the quality of data collected, offering insight into the driving forces behind population trends (CINAT UNA 2021, 64).

Other factors that native bee monitoring programs target in their research are foraging and nesting habitats, the impact of pesticide use, pathogens and parasites and genetics. When establishing trends for a native bee species in a particular area, it is also essential to monitor trends in weather patterns, plant growth, and soil quality over time (McKnight et al. 2018, 84).

These factors are major determinants of a population's health, and with the effects of climate change becoming more prominent, the landscape itself will be changing in more significant ways. In certain geographical areas, climate change may impact the occurrence and abundance of native species more heavily. Studying ecosystems that are more sensitive to climatic changes is very important in order to gather data on populations before significant changes begin. An example is a study by Whipple et al. (2022) that aims to determine which climate change effects are most heavily impacting pollinators found in high elevation ecosystems in Yellowstone and Grand Teton National Parks. Two teams were created to implement the study, one to assess historical data on the climate, and the other to study natural historical collections and plant/pollinator data obtained from the protected areas (Whipple et al. 2022, 1). Approaching a study, while mindful that collecting data on multiple factors besides the occurrence of specimens, will create higher quality results and can help researchers determine the resources to successfully implement the program.

Programs designed to protect or conserve a population of native bees in an agricultural setting often use regenerative bee pasture principles, such as allowing for blooming season to occur before livestock graze an area and caring for underground biodiversity which contributes to healthy soil and ecosystems (fungi, worms and bacteria). Higher soil quality and increased nutrient density increases the diversity of microbes in pollen, which is beneficial to the health of native bees and overall biodiversity of the environment (Red-Laird 2020). Kremen et al. (2002) and Landaverde-González et al. (2017) evaluated the effects of different landscapes on native bees, paying attention to flower/insect interactions and how populations behave in differing ecosystems. For threatened populations, the addition of water sources and native floral habitat resources can act as a natural solution for increasing the diversity and the richness of native bee species (Dibble et al. 2018, 17).

Botanists or ecologists working with entomologists bring knowledge of native plants and plant/pollinator relationships. The inclusion of experts who specialize in native plants can aid scientists or whole programs in identifying gaps in knowledge and baseline trends that were previously lacking. These data can also give researchers information as to the bees that might be present on certain flora, if there are no taxonomists available to immediately identify the bees. Gathering data supplemental to the species being studied can pinpoint why a species may be in decline (Hopwood et al. 2015, 11; Dibble et al. 2018, 17).

Monitoring as many ecosystem functions as possible will also help researchers gain a complete picture of the incline or decline of a species. Directed conservation actions may be taken if a program establishes data and trends showing the causes of population change.

Monitoring Native Bee Populations as Indicators of Larger Environmental Change

Anthropogenic impacts like deforestation and industrial development have created significant habitat loss for bees and exacerbated the effects of climate change, and with many life history traits and species-plant relationships unknown, it is increasingly important that these habitat interactions are prioritized in monitoring (Dibble et al. 2018, 21). Agriculture is the world's largest contributor to deforestation and one of the biggest causes of loss in species biodiversity: it acts as a key motivator for monitoring native bees in North America, and also for implementing conservation or restoration efforts to support these species (Briggs & Brosi 2013, 1210). Many native bee species are specialists, using resources from only a specific type of plant or food crop, which increases their sensitivity to changes in the surrounding environment (Schindler et al. 2013, 54 –55; Dibble et al. 2018, 4). Data establishing long-term trends on the changing structure of bee communities within agricultural systems are largely deficient but conducting environmental impact assessments on landscape prior to establishment of activities can facilitate use of native bee populations to indicate change (Schindler et al. 2013, 63).

Studies on Various Types of Agricultural Disturbance

In southern Chiapas, Mexico, researchers examined the relation between coffee crop farms and local euglossine bee communities. Using baited McPhail traps and hand netting techniques, results showed that agricultural management systems, such as coffee farms, have a significant deleterious impact on the abundance and diversity of euglossine communities, and that using a polyculture approach in future systems can combat species loss (Briggs & Brosi 2013, 1211–1215).

Wild bee abundance and diversity and the production of honey in the northern Great Plains in North Dakota, United States, were positively correlated in landscapes containing various levels of floral resources and agricultural disturbance, meaning that locations with successful honeybee colonies also supported native bees. Crops that do not provide adequate forage resources for bees were shown to negatively affect overall diversity. Data suggest that conservation efforts dedicated to identifying which landscapes best support pollinators and maintaining those used for pollen and nectar sources, will sustain bee habitats and their populations which are otherwise affected by agricultural intensification (Evans et al. 2018, 162; Kremen et al. 2002, 16816).

In the Yucatán Peninsula of Mexico, the effect of a traditional agricultural practice, called the *milpa* system, on sweat bee pollination services was studied at 37 chili field sites, with varying levels of forest loss. The *milpa* system intercrops corn with other species, using slash and burn technology to prepare the land. Pan traps and direct samples from flowering chili plants revealed that overall species richness and diversity increased with higher surrounding areas of forest cover; however, sweat bee abundance was shown to increase with a larger proportion of low intensity *milpa* agriculture surrounding chili sites. While *milpa* agriculture can be beneficial in supporting ground nesting sweat bee populations, it may not be true for all other flowering crops. Furthermore, natural habitat may be the only environment that contains and supports sufficient resources for pollinators (Landaverde-González et al. 2017, 1814–1816, 1822).

Recommendations to capture trends of native taxa impacted by a changing environment

- Focus resources on studies that collect plant-pollinator relationship data, emphasizing interactions between species and plants/crops of economic importance (Allen-Wardell et al. 1998, 11).
- Devote more resources to the study of life history characteristics of native bees, including energy sources (pollen and nectar), and their ecological role in pollination (Allen-Wardell et al. 1998, 11).
- Inventory and identify native and non-native plants present in an area, mapping the existing areas of floral diversity and resources available for native pollinators (Hopwood et al. 2015, 13).
- Maintain forests surrounding crop fields to sustain diversity and habitat needs of pollinators (Landaverde-González et al. 2017, 1822).

3.6 Data standards

Making data from native bee monitoring programs available to the wider scientific community is one way to expand a program's impact, and this can be further enhanced if widely accepted standards are used for data collection and management. At this time, while most programs from the questionnaire consider their data open access or make it available when results are published, there is no single standard for how data will be collected, organized and maintained. As noted in Section 2.5, almost all native bee monitoring programs in North America today use their own institutional standards.[8] The potential for broader integration of these data to inform managers' or policy makers' understanding of changes to native bee populations, or the effects of land use, climate change and conservation efforts, is therefore challenged because the data collected cannot be readily combined (Wieczorek et al. 2011, 6). Standardizing bee inventory and monitoring efforts make it possible for multiyear efforts to compare data and identify management practices that apply to conserving pollinator health in similar ecosystems (BLM Bee Monitoring Project 2021). The Xerces Society is one example of an organization that facilitates data use by publishing detailed guides for the assessment, observation, identification, monitoring and restoration of pollinators and their habitat in a multitude of landscapes (Arapahoe County Extension 2023; Mader et al. 2010; Minnerath et al. 2014; McKnight et al. 2018; Ullmann et al. 2008; Vaughan et al. 2015; Ward et al. 2014), while the RCN is working to create a national platform to facilitate data sharing among regions in the United States (Woodward et al. 2020).

While sharing data may be desirable, the considerations that experts have identified in the questionnaire responses include:

1. Protection of sensitive species or locations. Many programs obscure the exact location of data collection when sensitive species or fragile habitats are involved to avoid potential harm.
2. Status of the data. Releasing raw/unreviewed data, incomplete datasets, or data without adequate accompanying meta data can create the potential for misinterpretation.

[8] During the CEC's 2022 workshop, the participants also identified the development of best practices for data standards as a future priority. It is also important to note that while data standards may vary by institution, some institutions cover multiple and diverse monitoring locations.

3. Data collected on private property may be subject to provisions in the agreement with the property owner that may include data restrictions. Obscuring exact locations where data were collected may be an option, but it should be explicitly stated in the metadata.
4. Honoring agreements with Indigenous governments or organizations regarding data sharing and use if data are collected on Indigenous lands and/or using Indigenous Knowledge.

Monitoring programs that are not using their own standards are most likely turning to the Darwin Core Standard for their data collection. Darwin Core Standard (along with Plinian Core, below) is originally the product of a nonprofit organization, Biodiversity Information Standards (TDWG)9, that seeks to unify a wide range of biodiversity data by using common terminology and file formats. Having a unified structure and terminology can facilitate the analysis of data across programs.

The Darwin Core Standard categories of terminology—summarized in Table 7—focus on taxa, presence and abundance.

Table 7. Categorical Summary of Generic and Simple Darwin Core Terms

Record-level Terms	Dublin Core terms, institutions, collections, nature of data record	
Occurrence	evidence of species in nature, observers, behavior, associated media, references	
Event	sampling protocols and methods, date, time, field notes	
Location	geography, locality descriptions, spatial data	Simple Darwin Core (flat)
Identification	linkage between Taxon and Occurrence	
Taxon	scientific names, vernacular names, names usages, taxon concepts, and the relationships between them	
GeologicalContext	geologic time, chrono-stratigraphy, biostratigraphy, lithostratigraphy	
ResourceRelationship	explicit relationships between identified resources (e.g., one organism to another, taxon to location, etc.)	Generic Darwin Core (relational)
MeasurementOrFact	Measurements, facts, characteristics, assertions, references	

Source: Wieczorek et al. 2011, 3

[9] The organization's original name was "Taxonomic Databases Working Group," and more information can be found at: <www.tdwg.org>.

The Darwin Core Standard can be expanded to include plant–pollinator interactions according to a set of 48 terms and a data model developed to promote the interoperability of pollinator data generally across temporal and geographic scales. These new additions, published in 2022, include terms and definitions narrowed down by experts from hundreds of examples already in use, which, if adopted by monitoring programs, can facilitate data sharing and help to fill knowledge gaps related to plant–pollinator interactions (Salim et al. 2022, 2).

> The Global Biodiversity Information Facility (GBIF), which refers to the Darwin Core Standard as delivering "a stable, straightforward and flexible framework for compiling biodiversity data from varied and variable sources," provides information about how to get started at: <www.gbif.org/darwin-core>.

It is also important to note that use of the Darwin Core Standard itself does not necessarily require any additional expertise by those collecting the data. It simply defines the structure and terminology used. The Oregon Bee Atlas and the Pennsylvania Bee Monitoring Program are two examples from the questionnaire results in which trained volunteers collect data using the terms and the structure of the Darwin Core Standard.

Plinian Core also provides a common terminology and framework for data collection and management, but in addition to biological information, for which it aligns with the Darwin Core Standard, Plinian Core includes, "legal, conservation and management" concepts (Pando 2018, 1). The Shutterbee program at St. Louis University is the only program in the questionnaire responses that currently uses Plinian Core as a data standard.

Developing and coordinating a national effort

Biologists, conservation practitioners and educators have united to develop The US National Native Bee Monitoring Research Coordination Network (RCN), a collaborative effort to draft and implement a national native bee monitoring plan in the United States, "to streamline and standardize existing monitoring efforts, to promote better use of the native bee data we collect" (RCN website, 2022). Coordinated by a small team of experts, the RCN is engaging US federal and local governments, community scientists, crop producers, universities, cooperative extensions, private industry and conservation organizations (Woodard et al. 2020, 4) and is serving as a "central location of information and connection, by providing protocols, suppliers, taxonomists, training opportunities, funding opportunities and more" (RCN website, 2022).

The RCN has identified that a future national monitoring program for native bees should:

- Be cost effective and well-designed
- Acquire data needed to inform conservation decisions
- Account for different perspectives
- Leverage existing efforts and infrastructure
- Develop through a stepwise process, incorporating ideas and information from the larger community (Woodard 2021, presentation)

Action areas have been identified to coordinate such an effort (Woodard et al. 2020, 3–4):

1. Define the scope, aims and cost of a national monitoring effort
2. Improve and better support the national capacity in bee taxonomy and systematics
3. Gather and catalogue data for accessibility and sustainability
4. Prioritize geographic areas based on a set of decision criteria that include buy-in from stakeholders

In 2021 and 2022, the RCN brought together hundreds of experts and practitioners in a series of workshops to discuss and mobilize researchers and practitioners. A roadmap for these workshops included gathering insight and assessing existing efforts and capacity that could then lead to future implementation of a national plan. The RCN is demonstrating that dedicated experts and coordination capacity can harness expert advice, build capacity, and develop a national program that incorporates hundreds of diverse activities at different scales. Without such a national effort, the ability to collect data, develop status and trends information, identify drivers and inform or assess conservation actions is impeded (Woodard et al. 2020, 2).

3.7 Emerging technologies

Innovative approaches are being developed to overcome some of the inherent challenges to native bee monitoring.[10] Emerging technological approaches include:

[10] Challenges are discussed in the CEC workshop summary (Appendix A) and recognized in the scientific literature. As discussed in this section, specimen sampling can be time- and resource-intensive, and often lethal (van Klink et al. 2022, 872). Nest locations are easily missed (Liczner et al. 2021, 2; Lye et al. 2012, 697). After collection, specimens need to be cleaned, pinned, labelled and sent to taxonomic experts before an accurate identification can be made. Taxonomic experts are few and overburdened (CEC workshop 2022). Specimens are then databased, a process that is expensive, time-consuming, and slows research advancement (Spiesman et al.

- **Molecular methods (DNA barcoding).** DNA metabarcoding can allow for processing many samples and species at once and can be time- and cost-efficient compared to traditional monitoring (van Klink et al. 2022, 877). It is also possible to use fragments of DNA found in environmental samples (eDNA), such as water, soil and air, and by using environmental RNA (eRNA) to further distinguish living from dead individuals (van Klink et al. 2022, 879). RNA sequencing can also provide information on metabolic capacities and gene expression at the time of sampling (van Klink et al. 2022, 879). Metabarcoding outputs must be mapped to reference databases such as the International Barcode of Life Data System (BOLD) or GenBank to link with existing species knowledge (van Klink et al. 2022, 880).

Beenome100

In 2022, the USDA Agricultural Research Service launched "Beenome100," a project to map of the genomes of at least 100 bee species, capturing the diversity of bees in the United States, representing each of the major bee taxonomic groups. Once a genome is mapped, the data becomes publicly available for scientists to work on linking functions to specific genes.

The data is housed in the "i5k Workspace@NAL," an online platform at the Agricultural Resource Service's National Agricultural Library, allowing scientists from many organizations to work cooperatively on bioinformatics.

Source: Agricultural Resource Service, USDA

- **Computer vision: developing algorithms to identify bees from photos.** Computer vision can recognize insects in photos and provide information on taxonomic identification, occurrence, abundance, individual size, biomass, movement and species interaction (van Klink et al. 2022, 873; Høye et al. 2020, 2). Accuracy rates can be over 90 percent at the species level for some insect taxa, but heavily depend on taxon group size and morphological similarity, and only identification of family or genus levels are possible in some contexts (van Klink et al. 2022, 874). Citizen science portals such as iNaturalist and Google Lens support automated identification; however, these apps are not yet accurate enough for research that requires species-level identification (Spiesman et al. 2021, 2). Spiesman et al. 2021 compared the accuracy and speed of four convolutional neural network classification models to identify 36 North American bumblebee species and found that the Inception V3 model provided a good balance between speed and accuracy.
- **Acoustic monitoring: algorithms to identify bees from acoustic recordings.** Acoustic monitoring uses sensors to collect sound information which is then combined with machine learning algorithms to identify species (van Klink et al. 2022, 874). It offers real-time monitoring opportunity over broad distances and in remote areas (Miller Struttmann et al. 2017, 8). It can provide information on behavior, phenology, ecological functions and courtship (van Klink et al. 2022, 875). Miller-Struttmann et al. 2017 tested the effectiveness of this technique to monitor bumblebee behavior and pollination services, finding that flight buzz density was predictive of wildflower reproductive success. They concluded that the sounds of bumblebee flight can be used to monitor bee activity and

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2021, 1; van Klink et al. 2022, 872). On a larger scale, "traditional monitoring is unable to provide even basic knowledge of the state of most insect species in most places" (van Klink et al. 2022, 872).

pollination services to bumblebee pollinated plants, which could provide real-time information to farmers (Miller-Struttmann et al. 2017, 10).

- **Radar.** Radar monitoring uses radio waves to detect insects in the airspace. It can provide detailed information on the shape, size, speed trajectory and even wing beat frequency on flying insects (van Klink et al. 2022, 876). This includes Light Detection and Ranging (LiDAR), which can detect insects much closer to the ground but has only recently been applied in entomology (van Klink et al. 2022, 877). Vertical-looking radars (VLRs) can provide data at a local scale and can give estimates of biomass and body shape, direction of flight, speed and body orientation. "However, VLR data provide little information on community structure, and conclusive species identification requires aerial trapping" (Høye et al. 2020, 2).

BeeMachine: using computer vision to identify bees

BeeMachine is a website where users can upload images of bumblebees and receive the top three species-identification predictions, denoting the likeliest species and a confidence percentage of each prediction.

BeeMachine:

- Currently recognizes over 100 *Bombus* species.
- Is based on over 313,000 images.
- Has a test accuracy of 93.7 percent, (but accuracy varies depending on the species, the level of morphological variability and number of training images).
- Is working on a user-friendly mobile app that can handle short videos and multiple images at once.
- Is updating its classification model to increase accuracy and to include more species in more regions of the world.

BeeMachine was based on work conducted by Spiesman et al. 2021 and is accepting images for use to improve the system.

- **Detection dogs.** Dogs have been used in a variety of conservation programs, including in recent studies assessing their ability to locate underground bumblebee nests that can be difficult to find. In 2019, researchers from York University teamed up with Working Dogs for Conservation to train dogs to detect bumblebee nests, then test those abilities in the field at locations in southern Ontario. While the dogs could identify nests in training from up to 15 m away, in the actual field test they had to be much closer (less than 1 m), leading researchers to conclude that dogs would benefit from *in situ* exposure to wild nests; however, these remain difficult for humans to find (Liczner et al 2021, 10). While this method shows some promise to locate wild nests, there exist many practical constraints that limit this practice as a viable method of monitoring at the moment (Liczner et al. 2021, 10–13). Further work needs to be explored to mitigate constraints (Liczner et al. 2021, 13).

Although each new development comes with its own strengths and limitations (see Table 8), some of which require further work to fully understand, embracing new approaches may help to expand the spatial, temporal and taxonomic coverage of native bee monitoring. As with the primary current methods described in Section 3.1, some emerging methods may also better serve some species' groups than others. For example, the need for large inputs to train machines to learn in computer vision means that species' identifications are going to best served by practical inputs, including frequently photographed/recorded species, such as *Bombus*.

Table 8. Current limitations of emerging technological methods related to native bee monitoring

Type of technology	Challenges for use
Molecular methods	• dependence on human labor for sample collection (van Klink et al. 2022, 877) • limitations to provide precise abundance or biomass estimates because DNA amounts and extractability vary across taxa (Høye et al. 2020, 7) • similarly, DNA amounts and extractability vary by taxa and may result in some species not detected despite being present (van Klink et al. 2022, 879–880) • commonly used genetic markers, such as those used to detect Hymenoptera sometimes fail (van Klink et al. 2022, 880). • sequencing errors, misidentifications and missing species can cause misclassifications when using reference databases (van Klink et al. 2022, 880).
Computer vision	• large amount of training data needed to establish algorithms, which could be improved with increased high-quality submissions of training data into systems (Spiesman et al. 2021, 8; van Klink et al. 2022, 874) • relatively large energy/power consumption from camera use and associated data transfer (could be mitigated by renewable energy use and edge computing or when processing is done on the device used for data collection) (van Klink et al. 2022, 874). • undescribed species will be challenging to identify (van Klink et al. 2022, 874, which could be addressed with open-source classification, where the machine could reject identifying a specimen based on a lack of information rather than identifying it incorrectly (Roady et al. 2020, 15–16)
Acoustic monitoring	• species identification will be limited to the size of the reference libraries, but which could be built up using citizen science (van Klink et al. 2022, 875) • there is a need to better develop an understanding into the factors that help detect insect sounds (equipment, environmental conditions, etc.) (van Klink et al. 2022, 875)
Radar	• improved algorithms to filter targets from other particles (and to better account for reflective surfaces on insects) are needed (van Klink et al. 2022, 877). • line of sight is necessary for local radar (Høye et al. 2020, 2–3).
Detection dogs	• dogs benefit from training with naturally occurring bumblebee nests, but difficulty remains in finding them (Liczner et al. 2021, 10–11) • confirming a nest find (via presence of resident bumblebees) in time to provide feedback to dog is challenging (Liczner et al. 2021, 11–12) • study designs and objectives limited to realities of working with dogs, such as fatigue and varying ability of different individuals (Liczner et al. 2021, 12–13)

Exploring conservation through use of a species group: stingless bees in Mexico

While native bee conservation often focuses on external management issues such as land use or pesticides, the revitalization of meliponiculture—keeping stingless bees—provides an opportunity to both conserve and better understand this culturally important native bee species group. Meliponiculture produces honey, pollen, wax and resin for various food, art and medical uses including the treatment of various diseases and ailments (González-Acereto et al. 2018, 261; Reyes-González et al. 2020, 3). While meliponiculture is growing in popularity, some are concerned that inexperienced practitioners may use practices that increase the likelihood of colony failure, such as moving colonies or spreading disease (Quezada-Euán 2018, 259, 262).

Investigating beekeeping practices to conserve stingless bees

While the resurgence in meliponiculture began in the 1980s (González-Acereto et al. 2006, 238; Quezada-Euan et al. 2018, 259), research efforts began focusing on this activity in 2000. Relying heavily on local knowledge collected through interviews, the studies have resulted in species-specific designs for beekeeping boxes; recommendations for training in methods to reduce wild collection (González-Acereto et al. 2006, 234–238); understanding of common practices and customs, as well as the language related to beekeeping processes; identification of 110 plant species that are important food resources for stingless bees; and recognition of the potential impact to stingless bees and beekeeping caused by the expansion of monocultural agriculture in the same regions (Simms et al. 2022, 717–727). Research has also resulted in development of rescue strategies for hives at risk from habitat destruction. Engaged practitioners in one project established the *Meliponicultores Michoacanos del Balsas*, a group dedicated to sharing knowledge and best practices for conservation strategies surrounding meliponiculture in the Balsas River basin region (Reyes-González et al. 2016, 208-218).

Some best practices to support meliponiculture include:

- systematically tracking and evaluating the number and location of meliponiculture projects, colonies, species taxonomy, genetics and outcomes (Quezada-Euán et al. 2022, 22)
- validating scientific information and making it available on peer-reviewed platforms through practical and accessible handbooks for practitioners (Quezada-Euán et al. 2022, 22-23)
- developing cooperative beekeeper networks with academia and government support and delivering courses with culturally relevant materials and taught by certified instructors that cover and respect Local Ecological Knowledge, and providing follow-up support (Quezada-Euán 2018, 261–264)
- considering natural biogeographic distributions of Meliponini, enhancing local support to halt moving colonies across regions and conducting routine sanitary inspections (Quezada-Euán 2018, 261–265; Quezada-Euán et al. 2022, 26–27)
- proposing hive boxes as alternatives to hollow logs, and designing hive boxes according to species-specific needs, while developing methods for controlling pests and parasites (Quezada-Euán 2018, 260)

- continuing to explore use of stingless bees for crop pollination purposes and developing certifications to ensure the integrity of products produced from meliponiculture (Quezada-Euán 2018, 262)
- studying the consequences of stingless bee exploitation in urban environments and developing information campaigns to raise public awareness on the implications of illicit trade (Quezada-Euán et al. 2022, 23)
- establishing and managing domestically kept stingless bees (Meliponini) as a way to help conserve this ecologically, economically and culturally important species group, of which 46 species are found in Mexico (Ayala et al. 2013, 135).

Figure 13. Traditional management of stingless bees in Michoacán, Mexico

Source: Image reproduced from Figure 4 in Reyes-González et al. 2020 with permission from authors. Figure depicts traditional management of stingless bees in Michoacán, Mexico. Clockwise from top left: Extraction of a wild nest of *Melipona fasciata*; Extraction of a wild nest of *Melipona lupitae* Ayala, in a *Cyrtocarpa* sp. tree; Extraction of *Nannotrigona perilampoides* Cresson, nest located in a cavity between a rock and the ground; Extraction of *Scaptotrigona hellwegeri* Friese, in the base of a dead tree.

4 Discussion

This phase of the CEC's Advancing Pollinator Conservation in North America project has focused on improving the understanding of current native bee monitoring programs, methods, and practices in North America, and becoming familiar with the work of diverse practitioners and researchers active in native bee monitoring. Information collected through this activity captures a moment in time in a constantly developing sphere of activity: expert questionnaire responses highlight predominantly new (and some long-term) monitoring programs; emerging technologies show promise to improve monitoring; and there is a significant effort underway in the United States to develop a national plan for native bee monitoring to inform future monitoring in that country (US National Native Bee Monitoring Research Coordination Network; RCN). Highlights from the virtual workshop report, questionnaire results and literature review include:

- **The need to better understand native bee diversity and well-being is recognized in light of concerns about pollinators overall.** However, broad-scale data for native bees (like most insects) are currently quite limited; geographic and taxonomic monitoring coverage is spotty and inconsistent. There is an enormous opportunity to advance the field of native bee monitoring, to empower our ability to track status and trends, and to create a legacy for future policy and natural resource management decision making.
- **While program managers and practitioners of native bee monitoring efforts may be scattered and diverse, there is a widespread willingness to share program information and contribute to coordinated efforts.** This was demonstrated by the willingness of participants to join the CEC virtual workshop, complete the questionnaire, and engage in ongoing processes for both the CEC and the RCN.
- **Monitoring programs should be designed to inform conservation and management decisions.** With a diverse set of actors involved in pollinator monitoring generally and native bee monitoring specifically, it is important that monitoring efforts identify relevant management questions to target monitoring in a way that will bring the greatest impact to pollinator conservation.
- **There is a need for resources to sustain long-term native bee monitoring.** With the many native bee monitoring programs initiated in the past few years in North America, there will be an increasing need to sustain programs intended for the long-term to maximize the understanding of native bee populations. Scaling up a coordinated, efficient, and strategic approach for monitoring broad-scale population status and trends for native bees will require leadership and coordination capacity, vastly more boots on the ground, data sharing incentives and enhanced data management platforms. A successful approach will also need to align efforts across government, academia, and non-governmental partners.
- **Research and monitoring coordination efforts can enhance monitoring results, and practitioners are encouraged to continue to engage in national and international coordination efforts.** Within the United States, this means engaging in the RCN effort that is currently ongoing. Experts from Canada and Mexico may also benefit from involvement in the process, or at least from considering the resulting framework for applicability in those countries as well. The CEC's work on pollinators conservation and an emerging Arctic pollinator monitoring coordination network also provide international mechanisms for coordination in North America.

- **Involving citizen scientists and other non-experts in data collection can expand monitoring coverage, but there will also always be a need for taxonomic expertise.** Native bee monitoring programs are widely accessible and there are exciting examples involving citizen scientists, gardeners, park guards, and other non-experts. The use of emerging technologies will enhance future capability to facilitate data collection, analyze data, and help eliminate some of the identification bottlenecks. Programs are encouraged to consider conducting volunteer analysis to recruit and retain volunteers, improve outputs, and encourage expert uptake of results.
- **Data standards and management should be aligned to facilitate analysis across programs and to assess status and population and distribution trends at larger scales.** Pending any forthcoming recommendations from the RCN as well as further discussions and processes under the current CEC pollinator project, the questionnaire responses indicate that the Darwin Core Standard is emerging as a focal point for such alignment.
- **Habitat, abiotic and climate data are essential components to monitoring native bees.** Without noting plant-pollinator relationships, landscape characteristics and/or changes in the ecosystem and climate, efforts to identify and attribute change in bee species' populations will be extremely difficult. Implementing appropriate conservation efforts may not be possible and may lack confidence without data on causes of decline.
- **Those in decision-making positions should seek to engage, understand, and support monitoring efforts**. Building connections between practitioners and decision-makers can give programs a platform to advocate for species and ecosystems requiring conservation action.
- **Continued trilateral coordination is needed in Canada, Mexico and the United States.** During the virtual workshop, there was general agreement that trilateral coordination on native bee monitoring is important. This may include building a trinational community of practice, continuing to share information, methodologies, best practices and data and work to ease logistical issues, such as movement of bee specimens across borders to facilitate taxonomic identification. Sharing information about emerging technologies and methods can be another potential point for North American collaboration in addition to the workshop recommendations.

5 Conclusion

This report provided a snapshot of native bee monitoring and related studies in North America and some considerations related to several common elements of monitoring programs. While it does not provide a prescriptive approach, it can serve as a reference for new programs or to facilitate partnerships across existing programs and, as such, should be considered in light of developments expected to be forthcoming from future CEC work on native bees and pollinators, as well as the efforts described to create a national plan for native bee monitoring in the United States and ongoing efforts in Canada and Mexico.

Appendix A: Summary of the CEC Virtual Workshop on Native Bee Inventories and Monitoring of May 2022

Virtual Workshop on Native Bee Inventories and Monitoring

Workshop Summary (3 and 11 May 2022)

Abstract

The Commission for Environmental Cooperation (CEC) convened a virtual workshop with native bee inventory and monitoring experts from Canada, Mexico, and the United States in May 2022. This workshop on native bees focused on identifying monitoring, survey, and inventory efforts across the continent, gathering lessons learned, identifying gaps, and laying the groundwork for potential future trilateral collaboration. Participants shared their insights and experiences regarding shared methodologies to track focal genera and functional groups, challenges and opportunities related to different monitoring approaches, data collection and management, the role of citizen scientists and volunteers, and the expertise needed for taxonomic identification. This workshop summary provides an overview of native bee monitoring, as shared by participants from each country, and key topics from the discussions.

Introduction

The Commission for Environmental Cooperation (CEC) convened a virtual workshop on native bee inventorying and monitoring in North America on 3 and 11 May 2022. The workshop, part of the CEC project *Advancing Pollinator Conservation throughout North America*, brought together more than 40 experts from government, academia, and nongovernmental organizations (NGOs) from Canada, Mexico, and the United States across two online sessions. This workshop was the first step in the CEC's work on native bees.

Workshop goals were to:

- Share knowledge on current native bee inventorying and monitoring efforts,
- Identify gaps in knowledge and shared priorities for native bee inventorying and monitoring protocols in North America, and
- Lay the groundwork to mobilize a North American network of experts to inform federal government decision-making.

A Steering Committee[11] of federal agency representatives is advising the CEC on this project. CEC and agency representatives welcomed participants at the start of the meeting with information about how the CEC works and their hopes for this project.

This summary:

- Provides information on the status of native bee monitoring in each country informed by breakout groups and reports,
- Identifies similar themes across the three countries discussed in workshop plenaries,
- Suggests options for future trinational cooperation on the issue, and
- Lists next steps for the project.

Workshop Participants

Workshop participants were identified by the Steering Committee. All participants are listed in Annex 1.

Thirty-five participants completed an introductory questionnaire designed to learn more about participants and their involvement in native bee monitoring and inventories. Contact information and self-reported biographical information was shared by participants. Almost half the participants identified themselves as coming from academia (46 percent), with others from federal governments, NGOs, and local/state/provincial government. Forty percent of participants came from the United States, 34 percent from Canada, and 26 percent from Mexico.

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[11] Gregory Mitchell, Environment and Climate Change Canada; Steve Javorek, Agriculture and Agri-Food Canada; Ryan Drum and James Weaver, US Fish and Wildlife Service; Esther Quintero, National Commission for the Knowledge and Use of Biodiversity (*Comisión Nacional para el Conocimiento y Uso de la Biodiversidad*—Conabio); Ignacio March, National Commission of Protected Natural Areas (*Comisión Nacional de Áreas Naturales Protegidas*—Conanp)

Figure 1 shows where participants were joining the workshop from, while Figure 2 shows the ecozones where their bee monitoring efforts are focused.

Figure 1. Map showing workshop participant office locations

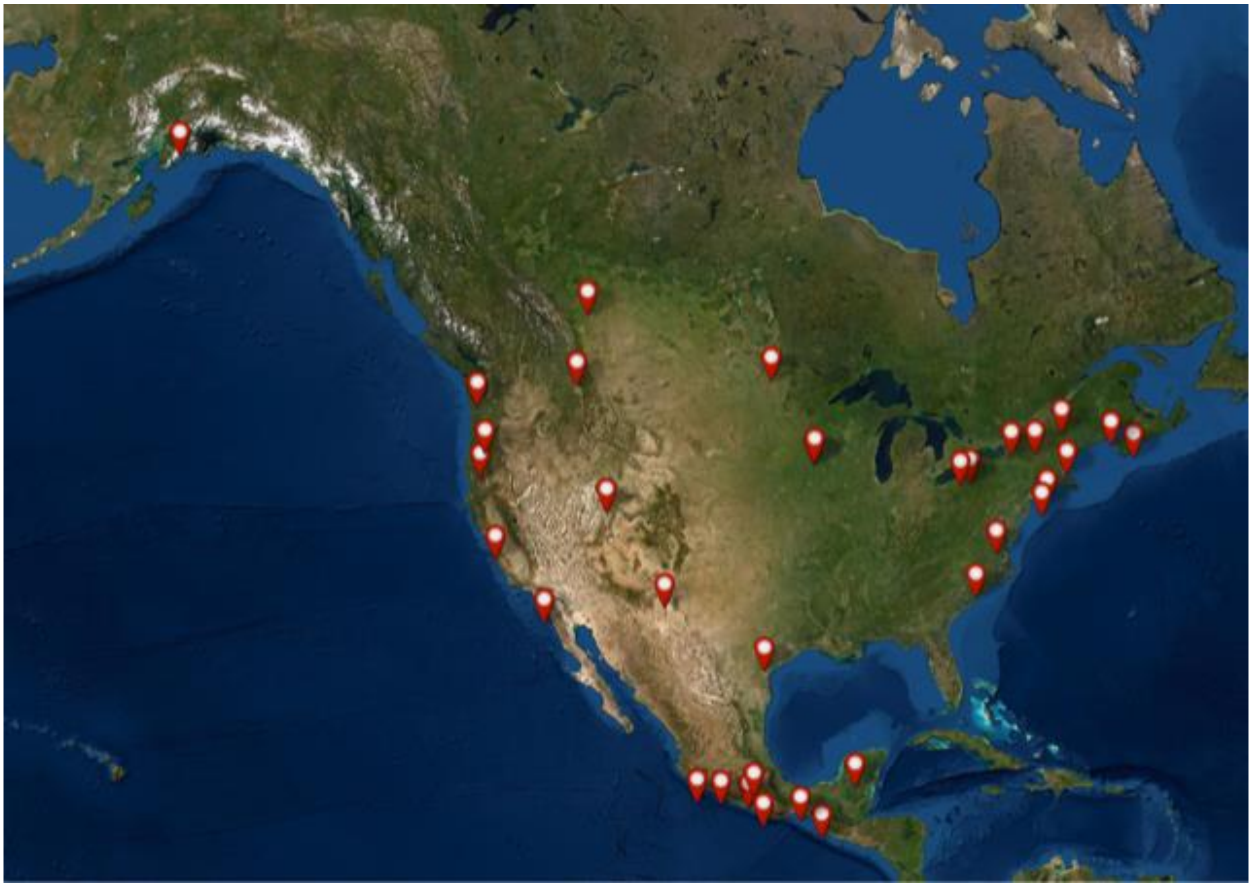
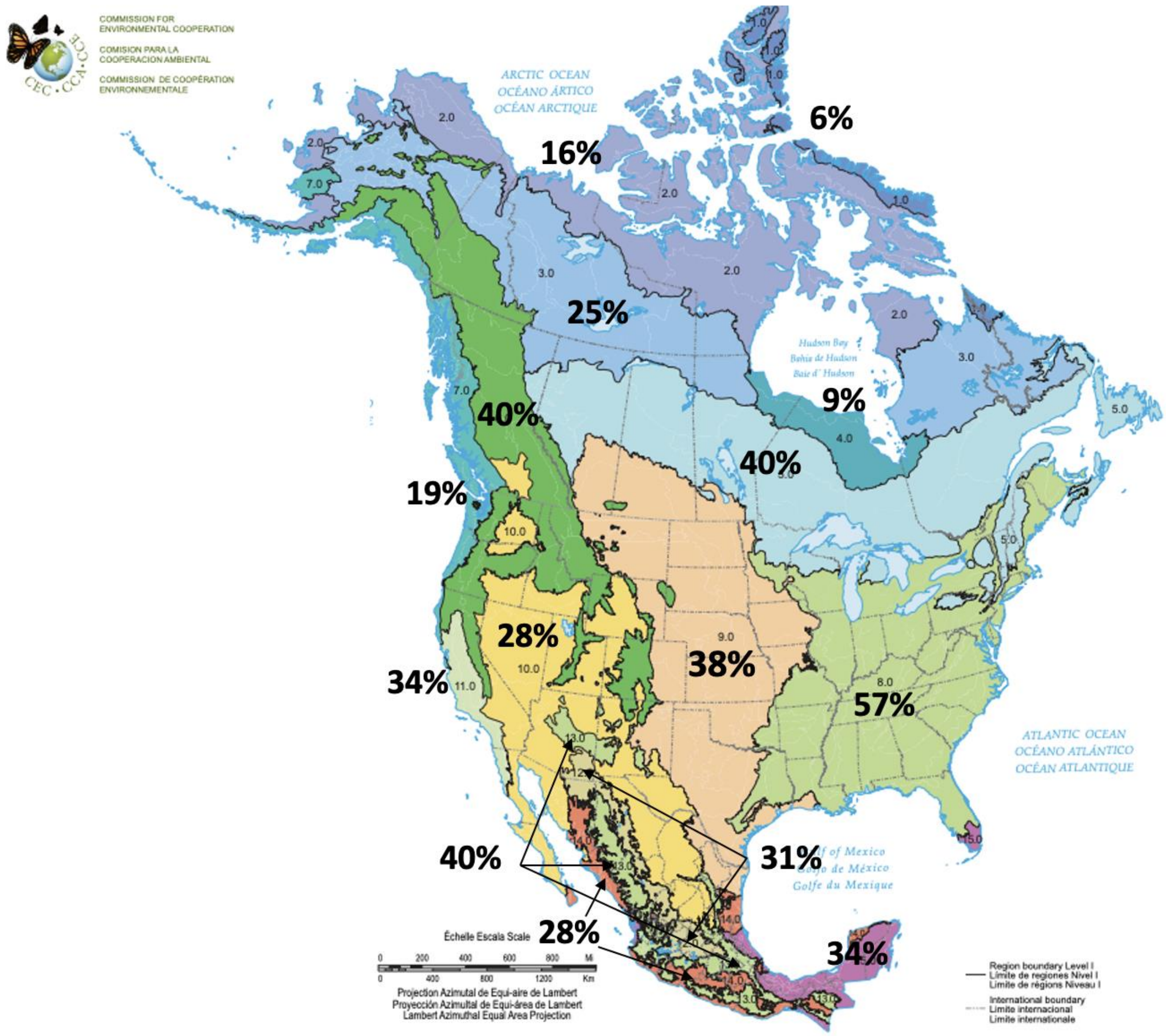


Figure 2. Percentage of participants (n=35) conducting native bee monitoring programs in each North American ecozones, based on introductory questionnaire



Note: Participants could select all ecozones where they conduct native bee monitoring efforts.

Status of Native Bee Monitoring by Country

Based on national breakout group discussions, a participant from each country characterized the status of native bee monitoring. Specific programs mentioned are listed in Annex 2. Common themes are captured in more detail in the Key Themes section.

Canada

- There is no coordinated national native bee monitoring plan or effort in Canada; however, there are diverse and extensive networks across the country focusing on native bees and/or the processes they support.
- Monitoring, survey, and inventory efforts are being conducted by universities, museums, NGOs, and governments (federal and provincial/territorial), and many involve citizen science efforts.
- There is a need to establish baseline data for native bees across many parts of Canada, i.e., developing inventories and determining abundance and species' richness. Status and trends cannot be determined at the moment across much of Canada, and for the majority of species, due to a lack of baseline data.
- Monitoring across Canada employs a variety of trapping methodologies because different methodologies have different efficacies for different taxa. Approaches include blue vane traps, pan traps, malaise traps, trap nests, and active netting. A combination of approaches may be an effective overall solution to give researchers widespread coverage at a community level. Many such efforts include community science activities.
- Attention to spatial and temporal coverage in monitoring program design is important, especially if results are to be compared.
- There are very few taxonomists with the required expertise, which creates a taxonomic bottleneck that impedes efficient and timely sample analysis.

Mexico

- Mexico recently published a National Strategy for the Conservation and Sustainable Use of Pollinators.
- Monitoring in Mexico is done by federal agencies (Conanp; Conabio; Semarnat, SADER), academia, and local communities.
- Many genera have been identified, but there is a lack of landscape and regional scales research.
- Cryptic species/lineages are important for conservation. Lineage characterization is of the upmost importance for the mobilization of stingless bee (Meliponini) hives.
- While some studies have been implemented for decades, there are significant gaps in the understanding of native bees in some areas, including:
    - Central and Northern Mexico (specifically Mapimi and parts of the Sonoran Desert—one of the richest areas for native bee diversity in North America)
    - Baja California Peninsula
    - Balsas River Basin
- The least-studied biomes are:
    - Temperate forests
    - Humid forests
    - Dry tropical forests

    - Deserts
    - Aquatic and emergent vegetation
    - Mesophilic forest
    - Grasslands
- Systematized information and knowledge are low.
- The National University of Mexico (UNAM) is developing an important research program on native bee distribution and diversity at national scale.

United States

- A US National Native Bee Monitoring Research Coordination Network (RCN) is underway now, being coordinated by the University of California, Riverside. The RCN has made significant progress identifying and engaging around 600 participants involved in bee monitoring programs across the United States.
    - The primary output of the US RCN will be a national monitoring strategy document in 2023/2024.
    - Four workshops have been held to date: (1) introduction to native bee monitoring, (2) conservation goals for national native bee monitoring, (3) US federal agency needs and priorities, and (4) Cooperative Extension and community science in native bee monitoring.
- Native bee monitoring programs are conducted by federal agencies, states, academia (including Cooperative Extension programs based at land grant universities), and NGOs. Prior to the RCN, there was no central point of coordination among these diverse groups, so much of the work now is focused on understanding and mapping the existing programs.
- In the RCN discussions there has been great interest in involving community science, or citizen science, but also in recognizing the challenges involved in incentivizing sustained participation, ensuring the accuracy of the data collected, and addressing biases that may be associated with community science.
- It is important to record plant associations when monitoring, as is compiling additional information on stressors and ecology.
- Data accessibility should be a priority. Data scientists are needed who can bring an understanding of the scope and flexibility of possible data platforms. (This was discussed further among all three countries.)
- Federal agencies express interest in a centralized data repository, but there are 10 agencies involved and coordination is just beginning. The US Department of the Interior has just created a Pollinator Conservation Coordination Group of its agencies doing relevant work.
- A national inventory is needed to establish the baseline population status of as many native bee species as possible.
- There is a taxonomic bottleneck and strategies are needed to relieve this. This also relates to funding.
- There is a need for a deep dive data semantics model to understand connections and commonalities. This will be a massive undertaking but is needed in order to begin making comparisons across datasets.

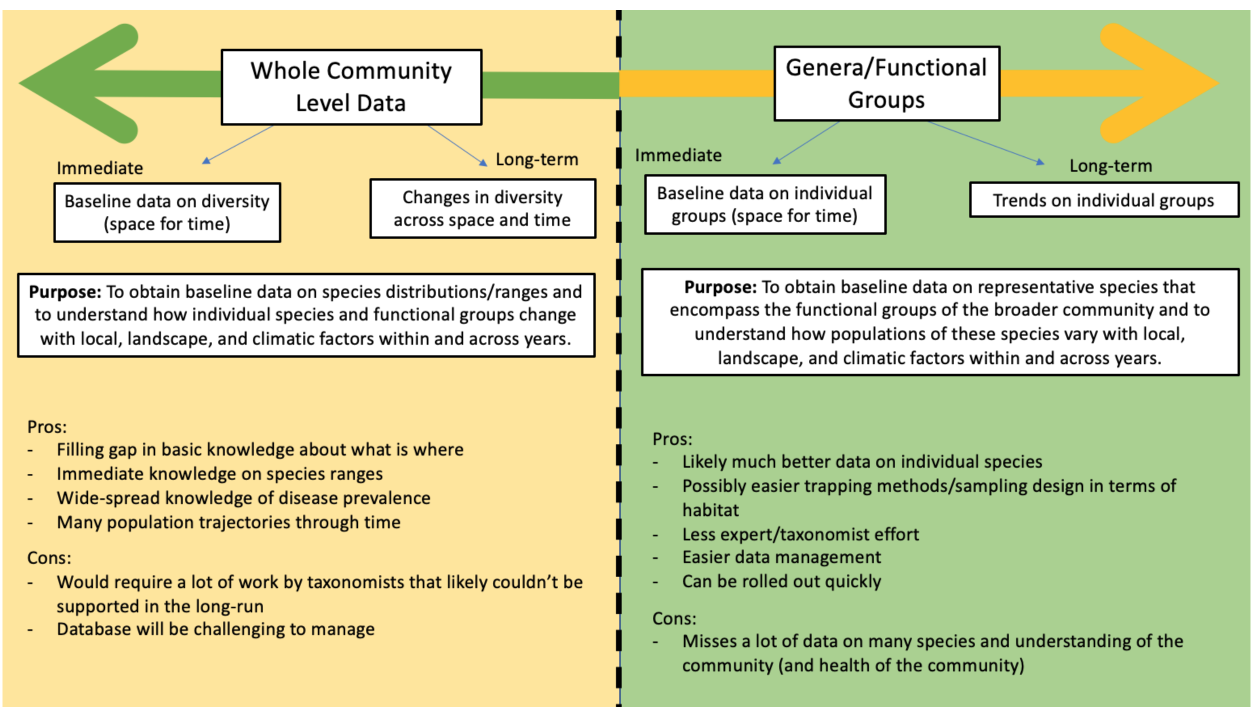
General Approaches to Native Bee Monitoring

There are many approaches to native bee monitoring. Greg Mitchell (Environment and Climate Change Canada and Steering Committee representative) presented a generalization of these approaches on 11 May, based on the discussion of 3 May, shown in Figure 3.

The arrows represent the spectrum between the two general approaches which focus on "Whole Community Level Data" (left) or "Genera/Functional Groups" (right). The figure below was put forward for the purpose of having a common language for the discussions during the first day of the workshop and to aid further discussion amongst participants. It was acknowledged that if the group were to develop a common monitoring program, much more work would be needed to ensure a shared understanding of the definitions, variables, and scales for use. Further considerations include perspectives on: (1) definition of scale (space and time), (2) levels of organization (e.g., community, populations, species), and (3) attributes or response variables by the level of organization (abundance, richness, detection, occupation, etc.).

When asked to identify how participants' existing monitoring efforts could fit within this conceptual framework, 10 participants indicated they use a combination of the approaches above. Nine focused on the whole community, and seven said they focused on genera/functional groups.

Figure 3. Generalized description of two main monitoring approaches



Source: developed by Greg Mitchell after Day 1, and modified based on input on Day 2

Key Themes

This section summarizes key themes and comments from the plenary discussions on both days of the workshop, as well as on issues contained in the three country reports of 3 May.

1. Cross-border collaboration is valuable, even if there are many challenges

Participants expressed interest in opportunities to work more closely on these issues across countries and saw value in continuing cooperation under the CEC and amongst themselves.

Discussion of important considerations for cooperation yielded the following points:

- Cooperation provides opportunities to learn from others to improve program development and implementation.
- The three countries contain complementary expertise that could be leveraged for a trinational effort.
- Historical data from one area/region can inform others who are seeking to manage bees in similar habitats.
- Even if native bees do not always cross international borders, viruses, pathogens, and parasites may. It is important to monitor for these and share information.
- The three countries could consider conducting a program similar to one in Costa Rica done to train staff and local people on data collection (parataxonomists/parataxónomos) at protected areas on the Guanacaste Peninsula. The Oregon Bee Atlas in the United States is another example of a program that trains members of the public as parataxonomists.
- There is an emerging effort to coordinate Arctic pollinator monitoring under the Arctic Council's Conservation of Arctic Flora and Fauna working group.
- There would need to be agreement across programs and countries on the methods for data storage, mobilization, and multi-scalar analysis, while allowing for contextual flexibility.
- There may be opportunities to train and supervise students across borders as a way of exchanging methods and results.

2. The diverse and distributed network of actors makes it challenging to get a comprehensive picture of trinational native bee monitoring and inventory efforts

In the three countries, native bee monitoring, inventories, and other research is undertaken by government agencies at different levels, academic institutions, and NGOs.

- Inventory and monitoring efforts are motivated by disparate mandates or organizational missions and funded by diverse sources.
- While the US RCN is making significant progress in this direction, none of the three countries currently has a nationally coordinated monitoring plan for native bees.

3. Baseline data on bee abundance and species richness is lacking for many areas

Even while many monitoring efforts are underway, participants in all three countries identified gaps in knowledge for baseline data, i.e., abundance and diversity of bee species in a given area.

- Example gaps mentioned:
  - Native bee species presence is unknown for more than half the protected areas in Mexico
  - There are known gaps in northern Mexico and the Baja California Peninsula
  - Arctic areas
- Some areas of Canada have been highly sampled for native bees, but many areas are under-sampled.
- Gaps exist for many reasons, including a lack of institutional focus/priority, cost, security/safety, permitting, and more.
- In Mexico, species lists are incomplete for more than half of the natural protected areas. Many of the 140-150 studies of native bee populations are for the same small number of species (an estimated two to five percent of roughly 2000 species).
- Studies in Canada, particularly when focused on agricultural areas, have been on relatively short timeframes. This makes it difficult to identify trends amidst natural population and seasonal cycles. Longer-term trend data needed to understand the impacts of land use change and climate change on bee communities is missing, but the baseline understanding of “what bees are where” is the critical first step.

4. Current monitoring programs focus primarily on native bee status and trends, but also try to address a variety of needs

When asked about the primary purpose of their monitoring programs, 14 of 26 respondents on May 11 indicated "status and trends of native bee populations" while the next highest number of respondents (six) indicated "manage habitats to promote healthy native bee populations."

- Workshop participants explained their programs may be seeking to describe status and trends, for example, but may not have adequate data to do so at this time for most species. This could be because taxonomy is vastly under-funded and thus taxonomic identifications are not reliable or have resulted in a backlog.
- Programs may be intended to meet multiple purposes, particularly by using status and trends to inform management and decision-making at different levels.
  - In Alaska, for example, the Alaska Bee Atlas native bee monitoring program seeks information on status and trends, but the ultimate purpose is to inform management decisions related to species and habitat.
  - The Endangered Species Act in the United States is a driver for monitoring of specific species. While a goal may be determining status and trends, data may also be needed to inform recovery strategies, identify disease prevalence, assess genetics of a population (when considering future targets for reintroduction), or inform activities such as pesticide use and population management in general.
- It was suggested that a CEC effort could identify common information needs of habitat managers and other users of native bee monitoring data across the three countries.

5. There are many diverse proven sampling methodologies, the use of which depends on the purpose of the program

Different methodologies have different efficacies for different types of data collection. The methodology chosen for a particular program will depend on the purpose of the monitoring effort as well as other factors, such as the level of expertise of those collecting data as well as cost and feasibility. It was suggested that a combination of approaches may be a suitable overall solution to give researchers good coverage at a community level.

- While many sampling programs use lethal methods, there are also many successful models using non-lethal methods.
- Monitoring done for a regulatory purpose may need to be species-specific.
- When considering methodologies for comparative sampling, it is necessary to consider cost, feasibility, repeatability (for example, consider different levels of expertise of data collectors and the tools they need to employ high-skilled netting vs. lower-skilled pan traps), taxonomic coverage/biases, and the overall ability to answer the monitoring questions. Monitoring frequency within and between seasons must also be considered.
- There could be some sort of consistent phenological calibration for start date across ecozones (i.e., to connect with willow or dandelion blooming). Repeated longitudinal sampling is needed throughout the season.

6. Limited capacity for taxonomic identification affects program delivery, cost, and implementation

When asked about their greatest challenges in native bee monitoring programs, 22 of 27 participants responded that a “shortage of taxonomic identification capacity” was one of their top three challenges. “Funding” was the next most popular response, with the relationship between the two acknowledged (i.e., less capacity for taxonomic expertise makes it more expensive).

- Most programs have more specimens and samples than they have the time and/or capacity to process.
- There are complications when trying to move specimens between countries, as transboundary biological permitting processes may be difficult or time consuming to navigate.
- Some approaches to reducing the taxonomic bottleneck are to:
    - train more taxonomists
    - use molecular approaches (although barcoding can be expensive and even destructive for sample parts)
    - establish better and more consistent DNA libraries for barcoding in the three countries
    - reduce the amount of material needing identification or reduce the taxonomic resolution sought, i.e., focus on functional groups and/or ecosystem services, such as social ground nesters versus solitary ground nesters or kleptoparasitic bees
    - use indicator or focal taxa, but these must be selected carefully and may be inconsistent across wide geographic ranges

- Compared to all bees, the taxonomic bottleneck for bumblebees is smaller, because more experts are focused on this group and it includes fewer species. (This is also the case for carpenter bees and some other focal groups.)

7. There is some potential for shared focus on genera/functional groups across the three countries

The group did not attempt to agree on a genera or functional groups to focus on across the countries, but Table 1 shows the suggestions offered for potential future consideration.

Table 1. Potential genera or functional groups for shared focus across the three countries

Genera	Functional groups
Agapostemon *Nomia* *Osmia* *Anthidium* *Megachile* *Bombus* *Bombus vosnesesnkii*	Kleptoparasitic bees

8. Aligning data standards and management is needed to facilitate analysis across programs and to assess status and trends at larger scale

Participants expressed great interest in being able to compare data across programs, regions, and countries. Standardized protocols for data management can be developed to promote comparability and basic standards of data quality but must include options for different approaches and program contexts.

Obstacles to an integrated analysis of data from disparate programs and some suggestions for overcoming them are shown in Table 2. It was noted that these challenges are not necessarily specific to native bees, but apply to biodiversity data, in general.

Table 2. Obstacles and suggestions related to data interoperability across programs/borders

Common Obstacles	Suggestions
Limits on data accessibility Reluctance to share data until publication, or perhaps at all Data are kept in separate locations (e.g., US federal agencies keep data in different places) Structures built to assemble data may not be user-friendly	Agree on a centralized database that allows data providers to have control over sharing (or, if national databases are used, make sure databases reference each other)

Lack of consistent standards Data tables may be incomplete (perhaps partially due to reluctance to share data) Data standards vary by institution	Agree on and use international standards for all programs Darwin Core (biodiversity informatics for specimens) Plinian Core (species level and species/plant interactions) Publish taxonomic data through the Global Biodiversity Information Facility's data papers or a similar tool

- Of the 20 participants who responded to a question about the accessibility of their monitoring data, only one indicated that their data are not available to others. Thirteen indicated that data are public when published, and nine participants provide open access to data. In three cases, data are public domain except when related to sensitive species. (More than one response was allowed.)
  - In Canada, there is a new effort to make data from government science projects available to the public.
  - There is a Canadian National Collection of Insects, Arachnids, and Nematodes (CNC) with an estimated two to three million Hymenoptera specimens. The CNC is developed and maintained by Agriculture and Agri-Food Canada.
  - US Department of Agriculture is working to get data online in real time.
  - In the United States, the RCN discussions have emphasized the need for a national database.
- Of the 19 participants who responded to a question about which data standards they use for their native bee efforts, 13 reported using their institutions' standards while eight use Darwin Core. Darwin Core has become a focus in the US RCN discussions. Plinian Core is also used in Mexico, but neither was identified as in use in Canada.
  - In Mexico, Conabio has further developed the interaction item in Plinian Core (PLiC) that includes pollination, including controlled vocabularies. This can be shared and is in the process of being published.
  - Ecosur has been consolidating a database on Mesoamerican bees, which presently contains 480,000 entries.
  - The US RCN is working on best practices for data standards for a range of program approaches.

9. Citizen scientists and non-experts can be critical to expanding the spatial and temporal scales of data collection

Strong emphasis was placed on harnessing the power of citizens to improve the spatial and temporal coverage of monitoring programs; however, program design needs to consider the unique opportunities and challenges to utilizing citizen science.

- Diverse groups of people are involved in collecting data on native bees across three countries, including both experts and non-experts. It is important to establish appropriate and effective protocol(s) for non-experts.
- There may be a reluctance to lethally sample bees while using citizen scientists.

- Non-experts can collect photo-based observations of species over large geographic and time scales. The photo documentation of specimens may not be as good as having the actual specimens.

Opportunities for Trinational Cooperation

Participants identified the following initial steps towards enhancing the harmonization of native bee monitoring efforts in North America, again reiterating the need for funding for implementation.

Continue to build a trinational community of practice

- Build and reinforce structures to support ongoing and consistent communication between experts across countries. Use these structures to continue to identify shared goals and priorities while creating a shared awareness of diverse activities to monitor and inventory native bees across North America.
- Create opportunities for in-person meetings and knowledge exchange. The CEC is planning an in-person workshop for the fall of 2022, but experts may also find value in holding side meetings at conferences such as the Mesoamerican Conference on Native Bees or the North American Pollinator Protection Campaign, for example.
- Create an accessible resource for sharing information about what is happening in the three countries and who to contact for more information (e.g., a webpage as part of an existing effort or dedicated website).
- Seek opportunities to share supervision of students with universities in different countries. Student work can encourage information sharing and collaboration while training the next generation of scientists.

Continue to explore ways to share and use data across borders

- Share current databases with experts across borders, even if there are obstacles to synthesizing analysis at this time.
- In pursuing opportunities to share data, it is important to understand and address reluctance to do so. Developing shared terms for data sharing is one way to address concerns; for example, in the CEC's Trinational Monarch Knowledge Network, researchers have options to restrict use of their data, which may have encouraged participation.

Continue to identify ways to increase capacity for taxonomic identification

- This issue requires further exploration but was raised frequently. One suggestion for trinational effort was to identify mechanisms to facilitate moving bee specimens across borders for taxonomic identification, particularly shipments from Mexico to the United States. The need for funding was also mentioned.

Annex 1 - Participant List

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Courtney Price – *Moderator*

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Attended on 3 May only

* Attended on 11 May only

Annex 2 – Programs identified

The US breakout and report-back focused on the US National Native Bee RCN, which identifies many native bee monitoring and inventory efforts through its membership and workshop recordings. Programs mentioned for Canada and Mexico in this workshop are listed below.

Canada

- Canadian National Collection of Insects, Arachnids and Nematodes (CNC)
- Bumble Bee Watch
- Living Laboratories Initiative and Network
    - Atlantic
    - Eastern Prairies
    - Quebec
    - Ontario
- Alberta Native Bee Council
- University of Calgary
    - Bee Habitat Pilot Project (University of Calgary)
    - Calgary Pollinator Count (University of Calgary)
    - Beneficial Insects Surveillance Network (2015-2019)
    - Beneficial Insects Surveillance Network II (2019-?)
    - Mindi Summers (urban bees)
- York University: Sheila Colla's Native Pollinator Research Lab
- Insectarium
- Pollinator Partnership Canada
- University of Cape Breton: Alana Pinder
- University of Manitoba:
    - Jason Gibbs
    - Kyle Bobiwash
    - J.B. Wallis / R. E. Roughley Museum of Entomology
- Agriculture and Agri-Food Canada
- Environment and Climate Change Canada
- Royal Saskatchewan Museum
    - Bees of Canada, Cory Sheffield
- University of Guelph
    - 1 in 3 mouthfuls, Nigel Raine Lab
- Brock University: Miriam Richards

Mexico

- Instituto de Biología de la Universidad Nacional Autónoma de México (IBUNAM):
    - Chamela (1984-current): faunal studies in western Mexico and also Yucatán, in dry and temperate forests; not a periodic monitoring but can be used as a baseline.
    - South Central Mexico: faunal composition (taxonomy and systematics) of bees native to humid tropical regions (Tuxtlas), particularly orchid bees. Temporal resampling for trends.
- Instituto de Investigaciones en Ecosistemas y Sustentabilidad (IIES-UNAM)(30 years of studies): effects of forest fragmentation on pollinators, ecosystem services, mainly in the Neovolcanic Axis, in Chamela and in highlands.
    - Agricultural-wildland interface to demonstrate the importance of NPAs, risk factors and factors of pollinator use.
    - Project of 4 researchers to work on the use of native and honey bees.
    - Abejas de calabazas: Conservation, Ecology and Genetic Aspects.
    - Analysis of honey bees throughout the country: determining where they come from.
- Instituto de Ecología, A.C. – Centro Regional del Bajío (INECOL Pátzcuaro): Milpas, Cofre de Perote, Veracruz, agricultural systems in Lake Chapala.
    - Collaboration with Conanp on participatory monitoring in the Barranca de Cupatitzio, especially with species that are easy to identify in avocado-growing landscapes, together with UMSNH, with species that are easy to identify, especially *Bombus* and carpenter bees.
    - Annual public outreach events on the importance of native bees.
    - Publication of Guides.
- Universidad Autónoma de Yucatán (UADY): 20 years studying diversity of Meliponini (morphometrics, cuticular hydrocarbons, microsatellites and barcoding) that are very important in the Yucatan Peninsula and elsewhere in Mexico, particularly *Melipona beecheii* and *M. yucatanica*, but also *Scaptotrigona hellwegeri*, *S. mexicana*, *S. pectoralis* and *Nannotrigona perilampoides*. Important genetic lineages that merit conservation in different geographic regions across Mexico have been found. New threats related to the "stingless bee boom" are a present concern.
- El Colegio de la Frontera Sur (Ecosur):
    - Biocultural richness of Meliponini of Oaxaca between 2012 and 2018 in about 70 local communities to document their knowledge.
    - Faunal listings.
    - Detected that local people perceive that there are fewer bees.
    - Made inventories of the species of these groups, as well as documenting their management.
    - Focused on an outreach book.
    - Local people are the main actors for the conservation of bees.

Appendix B: North American Native Bee Programs

Tables below were compiled from the online questionnaire sent to workshop participants and their networks and are not suggested to represent an exhaustive list. Information is provided here to facilitate collaboration or sharing among programs.

Key:

Goal	General Habitat	Sampling Method(s) Used	Data Collectors	Data Standard
M = Monitoring S = Survey I = Inventory T = Taxonomic reference collection	U= Urban A = Agricultural N = Natural O = Other	B = Bowls V = Vane N= Net P= Photo O = Other	E = Experts, CS = Citizen Scientists or public NE = Other Non-Experts	I = Institution D = Darwin Core P = Plinian Core O = Other

Canada

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Abeilles citoyennes	M, S	Quebec	U, A, N	Diversity, abundance	n/a	n/a	B	E, CS	n/a	All	2019–2021
Bee Biogeography in Maritime Canada	S, I	Maritime Canada	A, N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, V	E, NE	I	All	2020-ongoing
Beneficial Insects Surveillance Network	S, I, T	Alberta, Canada (330 sites distributed across the prairie grassland and parkland natural regions). Montane and alpine sites in Alberta and British Columbia (40 sites)	A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	Bumblebees (Mountain work) All species (Agricultural work)	B, V	E	I	All	2015–2019
Bumblebee queen emergence surveys, examining the impacts of environmental stressors on bumblebee movement	M, S	Guelph and Cambridge, Ontario	N, O	Diversity, presence/ absence, abundance, phenology, flight paths, turning angles, habitat selection	n/a	Bumblebees	N, O	E	I	None	2021-ongoing
Cape Breton University Bee group	M, I, T	Nova Scotia	U, A, N	Diversity, presence/ absence, abundance	Pollination	n/a	B, N	E, NE	I	All	2021-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Colla Lab (Ontario field work, Bumble Bee Watch, government protocols/frameworks)	M, S	n/a	U, A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	Pollination, Competi-tion	Mainly Bumblebees, but other wild bees depending on the project	B, N, P	E, CS	I	Some	2015-ongoing
Great Sunflower Project	M	n/a	U, A, N	Visitation rates	Pollination	n/a	P, O	CS	I	None	2008-ongoing
Long-term monitoring of bees in Niagara Region, southern Ontario, Canada	M, S	Niagara Peninsula, southern Ontario, Canada	N, O	Diversity, presence/ absence, abundance, phenology, body size	n/a	Bees that jump into pan traps	B, V, N	E, CS	I	All	2003-ongoing
Native Pollinator Initiative - Bumble Bees	M, S	Southern Ontario	U, N	Diversity, presence/ absence, abundance	n/a	Bumblebees	N	E, CS, NE	I	None	2012-ongoing

Mexico

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Bees from Northeast Mexico	M, I	Nuevo León and Coahuila in México	U, A, N	Diversity, Abundance, Plant-insect relationship	Floral visitors	n/a	B, N, P	E	I	All	2019-ongoing
Conacyt 103341 Conservation of stingless bees in Mexico and Conacyt 291333 Sustainable management of pollinators	M, S	Tropical regions of México: Yucatán Peninsula, Pacific Coast and Gulf Coast	U, A, N	Diversity	Pollination	Stingless bees and euglossines	N, P	E	n/a	Some	2010-ongoing
Diversity of orchid bees (Hymenoptera: Apidae) from the Mexican tropics through comparative monitoring of local populations and analysis of the genetic structure of representative species	M, I	It is proposed to include data from several states in México: Veracruz, Chiapas, Oaxaca, Campeche, Yucatán, Quintana Roo, Puebla, Tlaxcala, Morelos, Guerrero, Michoacán, Hidalgo, Qurétaro, State of México	A, N	Diversity, Presence/ absence, Abundance, Phenology	Pollination	Orquid bees	B, N, O	E	I	All	2021-ongoing
Diversity patterns of the wild pollinators in neotropical landscape of the Mexican Central-West region	M, I	Central - Western Region of Mexico made up of the states of Aguascalientes, Colima, Guanajuato, Jalisco, Michoacán, Nayarit, Querétaro, San Luis Potosí and Zacatecas.	U, A, N	Diversity, Abundance, eco-morphological traits	Pollination	Apidae, Megachilidae and Halictidae	B, V, N, P	E, CS, NE	D	Some	2017-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Ecosur (The College of the South Border) – Bees Team	M, S, I, T	All of México with an emphasis on Oaxaca, Chiapas, Tabasco, and the Yucatán Península.	U, A, N	Diversity, Presence/ absence, Abundance, Phenology, Data intended for occupancy modeling	Pollination	Interested in all bees, but in particular bumblebees, stingless bees and carpenter bees.	N	E, CS, NE	I	All	1986-ongoing
Great Sunflower Project	M	n/a	U, A, N	Visitation rates	Pollination	n/a	P, O	CS	I	None	2008-ongoing
Southern Mexico Coffee Pollinators	M, S, T	Southern Mexico	U, A, N	Diversity, Presence/ absence, Abundance, Phenology	Pollination	Focus on bumblebees, but otherwise all bees in the community	B, V, N	E	I	Some	2005-ongoing
Stingless bees and their keeping in Oaxaca, Mexico	S, T	State of Oaxaca	U, A, N	Presence/ absence, Data intended for occupancy modeling	n/a	Stingless bees	N	E	I	All	2012–2018

United States

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Great Sunflower Project	M	n/a	U, A, N	Visitation rates	Pollination	n/a	P, O	CS	I	None	2008-ongoing
Colla Lab (Bumble Bee Watch, government protocols/frameworks)	M, S	n/a	U, A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	Pollination, Competi-tion	Bumblebees, but other wild bees as well depending on the project	B, N, P	E, CS	I	Some	2015-ongoing
Cross Timbers & Edwards Plateau Texas Bee Survey, Central Texas Urban Pollinator Survey, Coast California Urban Pollinator Survey, Texas Cotton Pollinators	M, S	Central Texas, Coastal California	U, A, N	Diversity, presence/ absence, abundance, phenology	Pollination	Focus on bumblebees, but otherwise all bees in the community	B, V, N	E	I	Some	2012-ongoing
Alaska Bee Atlas	S, I, T	n/a	U, N	Diversity, presence/ absence	n/a	n/a	B, V, N, P	E, CS, NE	I, D	All	2020-ongoing
Arkansas Native Bee Inventory	M, S, I, T	Arkansas	U, A, N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, N, P	E, CS, NE	I	All	2021-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Bee Friendly Vineyards / Regenerative Bee Pasture	M, I, T	Oregon, North Dakota, South Dakota, Nebraska, Montana	A, N	Diversity, presence/ absence, abundance, phenology	Pollination	n/a	B, V, N	E	I	Some	2020-ongoing
BLM Bee Monitoring Project	M, I	Western U.S. States	N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	B, V, N	E, CS, NE	I, D	All	2021-ongoing
***Bombus affinis* Occupancy Study**	M	Minnesota, Wisconsin, Illinois	U, N	Diversity, presence/ absence, phenology, data intended for occupancy modeling	n/a	Bumblebees	P	E	I	Some	2021-ongoing
Bring Conservation Home project	S	St. Louis, MO metro (MO side only)	U	Diversity, presence/ absence, abundance, phenology	n/a	n/a	N	E	I	All	2020–2022

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Colorado State University/National Park Service Pollinator Hotspot Inventories	S, I	All natural resource inventory parks (span nationwide with the exception of Alaska) - 272 of the 400+ park units	U, A, N	Diversity, presence/ absence, abundance, phenology	Pollination	Bumblebees for 2021	N, P	E, CS, NE	D	Some	2021-ongoing; anticipated funding expires 2025
Crop pollinator monitoring	M	Vermont, New Hampshire	A	Diversity, presence/ absence, abundance	Pollination	n/a	P, O	E, CS, NE	I	None	2022-ongoing
Elizabeth Sellers - Banshee Reeks Bee Inventory	M, S, I, T	Banshee Reeks Nature Preserve (BRNP), Loudoun County, Virginia	N	Presence/absence	n/a	n/a	B, V	E, CS, NE	I	All	2010–2020
USDA ARS North Central Ag Research Lab	S, I, T	Brookings County, eastern South Dakota	N, A	Diversity, phenology, ITD	Pollination, Competi-tion	n/a	B, V, N, P	E	I, D	Some	2019–2021
Evaluation of Economic, Ecological, and Performance Impacts of Co-Located Pollinator Plantings at Large-Scale Solar Installations	M, S, I	Central Illinois, Central Indiana, Southern Wisconsin, Southwestern Michigan	A, N, O	Diversity, presence/ absence, abundance, phenology, honey bee (non-native bee) activity density	n/a	n/a	B, N, P, O	E	I	Some	2021-ongoing (through 2024)

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Impacts of habitat loss and fragmentation on extinction risk and population structure of bees	M, S, I, T	San Diego County - California	U, N	Diversity, presence/ absence, phenology, data intended for occupancy modeling	n/a	non-*Apis* bees	B, N, P	E	O	All	2011-ongoing
Indiana Dunes National Park Bee Resurvey	M, S, I	Indiana	N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, N, O	E, CS, NE	O	All	2003–2022
James Weaver	S, I, T	New Mexico	N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, N	E, NE	I	All	2022–2022
Janene Lichtenberg	I, T	Northwest Montana	N	Diversity, presence/ absence, phenology	Pollination	Bumblebees	N, P, O	E, NE	I	All	2016-ongoing
Katie Moriarty	M, S, I, T	Oregon, California	N, O	Diversity, presence/ absence, abundance phenology, data intended for occupancy modeling	Pollination, Disease	Bumblebees	B, V, N	E	I	All	2019–2023

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Kristin Gnojewski	S, I	Boise, Idaho	U, N	Diversity, presence/ absence	n/a	n/a	P	CS	I	None	2022-ongoing
Maine Bumble Bee Atlas (MBBA)	S, I	Maine	U, A, N	Diversity, presence/ absence, abundance, phenology, forage plant use, habitat	n/a	Bumblebees, Eastern Carpenter Bees, Giant Resin Bees, Wool Carder Bees	N, P, O	E, CS, NE	I	All	2015–2020
Meredith L Holm, USFWS	M, S, I, T	The Great Lakes Basin of the United States	U, N	Diversity, presence/ absence, phenology, data intended for occupancy modeling	Pollination	All Native Bees, but working to do a subset of surveys on bumblebees only	B, N, P	E	I	Some	2020-ongoing
Metamorphic Ecological Research and Consulting, LLC	M, S, I, T	West Virginia, Virginia	U, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	Bumblebees	N	E	I	All	2017-ongoing
Minnesota Wild Bee Survey	S, T	Minnesota	N	Diversity	n/a	n/a	B, V, N	E, NE	I	All	2015–2023

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Monitoring the effects of controlled burns on patterns of bumblebee abundance	S	Southern Wisconsin	N	Diversity, presence/ absence, phenology, data intended for occupancy modeling	n/a	Bumblebees	N, P	E	I	None	2022-ongoing
MPG Ranch long term bee monitoring project	M, I	Montana, Missoula County	N, O	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, N	NE	I, O	All	2013–2019
Native Bees of Natural Communities	M, I	Michigan	N	Diversity, abundance	n/a	n/a	B, N	E	I, D	All	2021-ongoing
Native bees of North America, taxonomy and biodiversity	S, I, T	Western United States	N	Presence/absence, abundance, phenology	n/a	All but with emphasis on Megachilidae, Rophitinae, & Perditini	B, N	E	D	All	1998-ongoing
NC Game Lands Bee Inventory	M	North Carolina	O	Diversity, presence/ absence, phenology, "abundance" to the extent that trap and net capture represent abundance	n/a	n/a	B, N, P	E, NE	I	Some	2018-ongoing
Northern New Mexico Refuge Inventory	S, I, T	New Mexico	N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, N	E, NE	I, D	All	2022–2022

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
NSF Bee Call - 2021/22	M, S, I, T	California	U, N, O	Diversity, presence/ absence, phenology, plant association	n/a	n/a	N, P	E	I	Some	2021–2022
Oregon Bee Atlas	I, T	Oregon	U, A, N	Diversity, presence/ absence, phenology	n/a	n/a	B, V, N	E, CS	D	Some	2018-ongoing
Pennsylvania Bee Monitoring Program	M, S, I, T	Pennsylvania	U, N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, V, N	NE	D	All	2021-ongoing
Photo pollinator surveys	M, S, I	West-Central and Central Illinois	N	Diversity, presence/ absence, abundance, phenology	Pollination, Competi-tion	n/a	P, O	E	n/a	Some	2018-ongoing (5-year rotational surveys)
Post-fire response of bee communities in Southwestern United States Sky Islands	M, I	Guadalupe Mountains & Big Bend National Parks, TX	N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B, V, N	E, CS	I, D	All	2018-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
RI Bumblebee Survey	S, I	Rhode Island	U, A, N	Diversity, presence/ absence, abundance, phenology	n/a	Bumblebees and large carpenter bees	N, P	E, CS, NE	I	Some	2022-ongoing (2024)
Sevilleta Long Term Ecological Research Bee Monitoring Project	M, S, I, T	Central New Mexico, Sevilleta National Wildlife Refuge	N	Diversity, presence/ absence, abundance, phenology	n/a	n/a	B	E, NE	I, D, O	Some	2001-ongoing
Shutterbee	M, S	St. Louis metro (Illinois and Missouri)	U	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	Pollination	n/a	P	CS	P, O	None	2020-ongoing
Shutterbee Citizen Science Program	S	Metropolitan region of St. Louis, Missouri	U	Diversity, presence/ absence, phenology, data intended for occupancy modeling	Pollination	n/a	N, P	CS	I	All	2020-ongoing
Tennessee Pollinators	M, S, T	Southeastern US, Tennessee	U, A, N	Diversity, presence/ absence, abundance, phenology	Pollination	n/a	N, O	E	I	All	2019-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
The Connecticut Bee Monitoring Program	M, S, I, T	Connecticut	A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	B, N	E, NE	I, D, O	All	2010-ongoing
The Ohio Bee Survey	M, S, I, T	Ohio	U, A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	B	E, CS, NE	n/a	All	2020
UCSBees	M, I, T	Santa Barbara, California	U, N	Diversity, presence/ absence, abundance phenology, data intended for occupancy modeling	n/a	n/a	B, N	E, NE	D	All	2016-ongoing
USDA Native bee monitoring project in soybean fields of Northeastern Arkansas	M, S	NE Arkansas	A	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	Pollination	n/a	B, V, N	E	I	All	2019-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Various surveys of bees in Central California and the Sierra Nevada	M, S, I	Central California	U, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	Sometimes bumblebees	B, N	E	I	All	2001 to 2020 - various - Marin County is ongoing
Western Kansas bee monitoring	M, I, T	Western Kansas	U, A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	B, N	E, NE	I	All	2019-ongoing
Xerces Bumble Bee Atlas Programs	M, S, I	PNW, California, MW, Great Plains	U, A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	Bombus	N	E, CS, NE	D	None	2018-ongoing
PhD candidate in Integrative Biology	S	California	N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	N	E	I	All	2020-ongoing

Project/Program	Goal	Sub-national region where data are collected	General Habitat	Native bee attributes monitored	Ecosystem function-related attributes (if any)	Focal bee group (if any)	Sampling Method(s) Used	Data Collectors	Data Standard	Specimen Storage	Duration
Oklahoma Native Bee Inventory	M, S, I, T	Oklahoma	U, A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	Host plant association	n/a	B, N, P, O	E, CS, NE	I	Some	2021-ongoing
Community structure of Palouse Prairie bees	I	Northern Idaho and adjacent Washington	A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	B, V, N	E	I	Some	2012-2013
One Tam Marin Bee Monitoring Project	S, I, T	Marin County, California	N, O	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	n/a	n/a	B, N	E, CS, NE	n/a	All	2017: 2021-ongoing
USDA/ARS Native Bee Surveys by the Pollinating Insect Research Unit in Logan, Utah	M, S, I, T	World-wide distribution with emphasis on the Southwestern USA	A, N	Diversity, presence/ absence, abundance, phenology, data intended for occupancy modeling	Pollination, Competi-tion	n/a	B, N	E, NE	I, D	Some	1946-ongoing

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