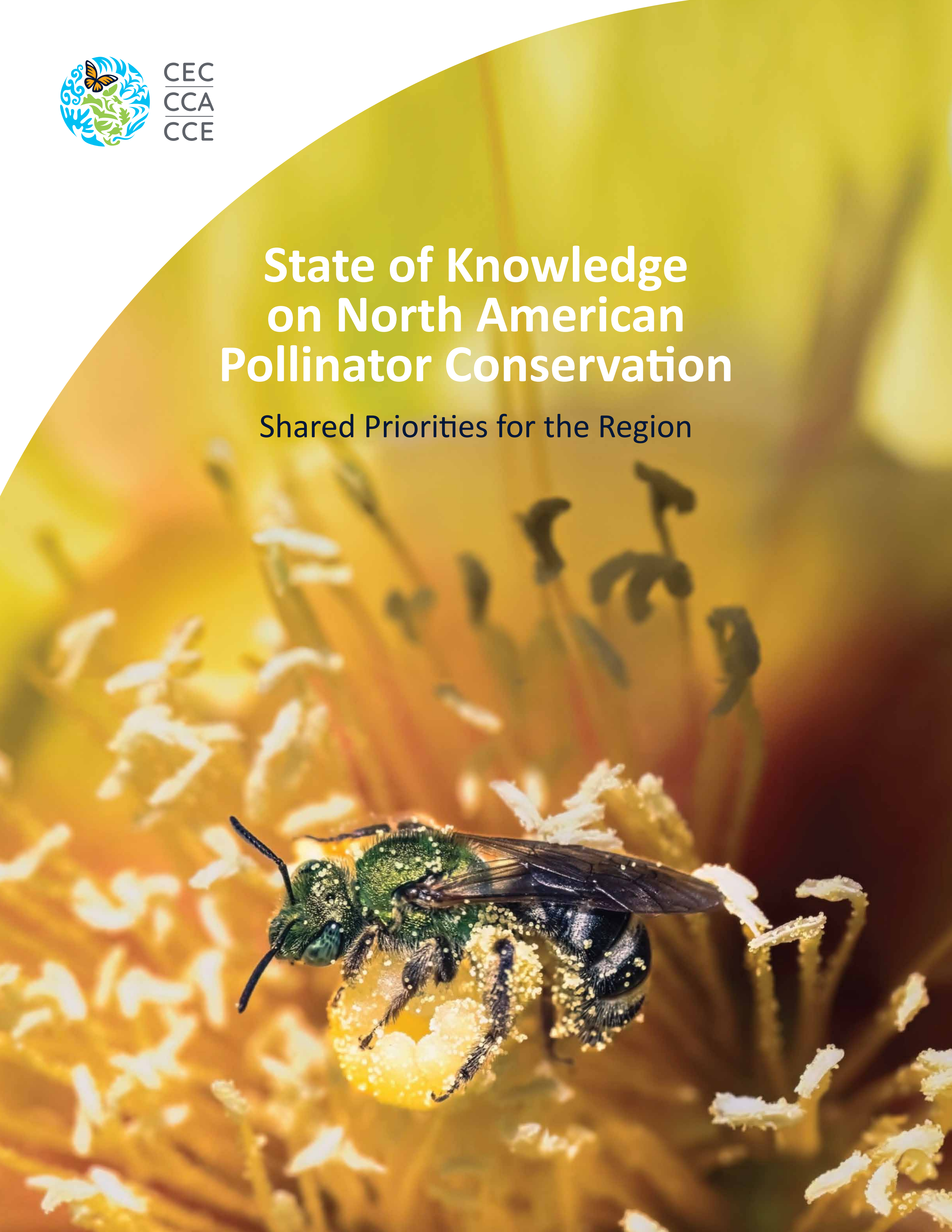
CEC
CCA
CCE

State of Knowledge on North American Pollinator Conservation

Shared Priorities for the Region



Please cite as:
CEC. 2024. *State of Knowledge on North American Pollinator Conservation: Shared Priorities for the Region.* Montreal, Canada: Commission for Environmental Cooperation. 54 pp.

ISBN: 978-2-89700-323-4
Disponible en français – ISBN: 978-2-89700-324-1
Disponible en español – ISBN: 978-2-89700-325-8

Legal deposit – Bibliothèque et Archives nationales du Québec, 2024
Legal deposit – Library and Archives Canada, 2024

Cover photo: Bicolored striped sweat bee (*Agapostemon virescens*), Wirestock

Publication Details

Document category: Project publication

Publication date: May 2024

Original language: English

Review and quality assurance procedures:

Final Party review: October, 2023

QA378

Project: Operational Plan 2019-2020 / Strengthening Regional Pollinator Conservation to Secure Local Benefits

For more information:
Commission for Environmental Cooperation
1001 Robert-Bourassa Boulevard, Suite 1620
Montreal (Quebec)
H3B 4L4 Canada
t 514.350.4300 f 438.701.1434
info@cec.org / www.cec.org

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

CEC	Commission for Environmental Cooperation
GBIF	Global Biodiversity Information Facility
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
IUCN	International Union for the Conservation of Nature

Abstract

Aware of the importance of pollinators for the North American region and of their observed decline worldwide, the Council of the Commission for Environmental Cooperation (CEC)—composed of the highest federal-level environmental authorities from Canada, Mexico and the United States—approved a series of activities on pollinator conservation under the 2019–2020 project, "Strengthening Regional Pollinator Conservation to Secure Local Benefits." As part of this project, the CEC Secretariat commissioned a state of knowledge on pollinators conservation in North America to inform and advance collaboration on pollinator conservation in the region. Further, the CEC convened two participatory workshops with government representatives and stakeholders from the three countries to identify knowledge gaps and priority areas for collaboration, while bringing attention to the socio-ecological benefits of pollinators and human dimension considerations.

This report presents the findings of the state of knowledge and the outcomes of the workshops and informal exchanges. After a brief overview (section 1), it offers a summary of the current understanding of species' diversity, population trends, and drivers of change (sections 2 & 3), including the high-level results of a quantitative assessment of observation records from the Global Biodiversity Information Facility (see Box 1 and Appendices). It highlights the ecosystem services supported by pollinators and explores how social sciences and human dimensions can contribute to pollinator conservation in North America (section 4). Each section identifies possible knowledge gaps and provides key messages in plain language. Finally, the report identifies priority conservation actions that would benefit from greater regional collaboration and provides recommendations on integrating human dimension considerations in pollinator conservation work (section 5).

Executive Summary

Pollinators are crucial to the functioning of natural ecosystems, human well-being, and food security. Pollination can be performed by many types of animals, ranging from insects like native bees, butterflies, beetles, ants, and flies, to non-insect pollinators, such as birds and bats, all of which contribute significantly to crop pollination.

The global decline in pollinator populations is attributed to multiple factors, including habitat loss and degradation, intensive agricultural management, pathogens, invasive species, climate change and the excessive use of agrochemicals, including pesticides (IPBES 2016, Wagner et al. 2021). Addressing this decline requires urgent conservation actions and the engagement of stakeholders across various sectors.

For more than a decade, the Commission for Environmental Cooperation (CEC) has supported trilateral cooperation for the conservation of the monarch butterfly across North America. Building on this previous work, the CEC's Council endorsed strategic actions for pollinator conservation under the 2019–2020 project, "Strengthening Regional Pollinator Conservation to Secure Local Benefits" including the CEC Secretariat commissioning a state of knowledge on pollinators conservation in North America and convening two participatory workshops with experts from Canada, Mexico and the United States. The *State of Knowledge on North American Pollinator Conservation: Shared Priorities for the Region* is the culmination of this work.

Section 2 of the report provides an overview of the status of pollinators in North America, in terms of species diversity, habitat distribution, managed and introduced species versus native species, and overall population trends.

The authors find there is a rich diversity of pollinator species across the continent. The extent of pollinator diversity and their population trends are still unknown, although some orders, families and genera are better documented than others. Most pollinators in North America are insects, ranging from bees, wasps and butterflies to flies and beetles. There are also some bird (hummingbirds) and bat pollinators, although the latter are only found in Mexico and the United States.

Baseline information on native populations of North American pollinators, as a whole, is quite sparse (National Research Council 2007) and diversity of wild pollinators is still only partially understood. As part of the research undertaken for this publication, the authors developed a database of assumed pollinator genera, based on a review of published literature and then retrieved observation records of those genera from the Global Biodiversity Information Facility (for details, see Box 1 and the Appendices). This database identified over 24,000 species of insect pollinators belonging to 2,829 genera in Canada, Mexico and the United States. Of these insect genera, 2,592 species had been recorded in the United States, 1,645 in Canada, and 1,082 in Mexico. The authors' assessment also found that the statuses of 1,159 of these species are of concern, as listed in international (59 species), national (35 species), or state/provincial (1,065 species) sources. Vertebrates of concern include four bats and seven hummingbirds, all ranked as Near Threatened, Vulnerable, Endangered, or Critically Endangered by the International Union for the Conservation of Nature (IUCN).

Published literature further highlights some of the variability of pollinator populations in North America. For example, there are 4,000 known native bee species in the United States alone (Kopec and Burd 2017, Moisset and Buchmann 2011) while Canada has more than 900 native bee species (Agriculture and AgriFood Canada 2014). The diversity of native bee species in Mexico is unknown, due to the levels of current sampling and gaps in knowledge; however, it has been estimated at over 1,800 species (Freitas et al. 2009).

A handful of pollinator species are actively managed: that is, are semi-domesticated, produced in large quantities, and bought and sold commercially (National Research Council 2007). Most of these are introduced or exotic species although some are native. The use of managed pollinators is a reflection of the importance of the ecosystem services they provide and also demonstrates that agricultural communities invest considerable resources in pollination services.

In terms of pollinator habitat, the authors' assessment has revealed that pollinators are found across all 15 North American ecoregions. More species are recorded in some ecoregions, such as the Eastern Temperate Forests in both Canada and the United States and the Temperate Sierras and Tropical Dry Forests in Mexico. However, pollinators remain understudied in many ecosystems and habitat types, and the ability to track population status and trends is limited by a general lack of data, along with geographic and taxonomic biases. Urban and agricultural areas are particularly well studied, but knowledge gaps persist in habitat types with lower human densities and for taxa that are cryptic and difficult to detect or identify.

While data on pollinator population trends in North America are generally limited, critical declines have been recorded for a few well-studied species, including wild native and managed species. Some species of butterflies, moths and bees have experienced population declines, though a few have increased. Some hummingbird species are also of concern.

Section 3 provides an analysis of the main drivers responsible for pollinator declines in North America. These include habitat loss, fragmentation and land use, competition from introduced species, pollution, pesticides and diseases, climate change, fire, and other factors. They impact pollinators of all taxa, in all habitat types, and can operate synergistically with one another (Brook et al. 2008), perhaps leading to nonlinear or multiplicative effects.

The most widespread and impactful driver of change for North American pollinators is habitat loss stemming from land-use change. In the United States, non-honey bees, butterflies, bats and other managed or wild pollinators are impacted by loss and degradation of habitat and for some species, there is strong evidence that habitat loss has caused population declines. For North American invertebrates included on the IUCN Red List, the most common listed threat is general habitat loss, followed by deforestation and climate change. Thus while there remain many unknowns, shared conservation challenges across the three countries would include addressing habitat loss and degradation spurred by expanding agriculture, urbanization, transportation, and energy corridors; introduced pollinator competitors, predators, diseases, and parasites; pollution and pesticide contamination; and climate change.

Section 4 reviews the importance of pollinators in the ecosystem services and benefits to communities that they render. The section also summarizes the results of a virtual workshop held in December 2020 that explored the human dimensions of pollinator conservation.

Pollinators benefit local communities in North America by contributing to all ecosystem services through their support of plant communities that underlie ecosystem function. Specifically, pollinators support agriculture, recreation, ecotourism, and culturally important plants and plant communities, making them fundamental to local community economies and even cultural identities. As pollinator communities fluctuate and species' assemblages change, it is unclear how ecosystem services will be affected.

Recognizing that pollinators are essential to functioning ecosystems and to the services offered by those ecosystems to local communities, developing conservation frameworks and approaches to address complex social-ecological systems requires a broad perspective that acknowledges the various aspects of ecological systems and the intersecting human use and interaction with those systems. Key ways for including the human dimension in conservation work include the involvement of social scientists, building relationships with local people, learning about different cultures, seeking out less obvious drivers and influences, learning continuously and adapting to change. Future work on the human dimensions of a conservation campaign or effort should focus on the messaging, type of events, and the strategies that can be introduced across the continent to advance pollinator conservation in a cohesive and effective way.

Based on the findings of this *State of Knowledge on North American Pollinator Conservation: Shared Priorities for the Region,* as well as on the outcomes of the participatory workshops convened by the CEC, section 5 of the report highlights the following priority areas for further collaborative work among the three countries:

- Prioritizing the monitoring of pollinators
- Prioritizing pollinator habitat conservation
- Researching agricultural practices and pesticide impacts
- Tracking and monitoring pesticide use
- Studying impacts of managed pollinators
- Monitoring trade and sales of managed pollinators
- Expanding education and alternative practices

- Identifying and developing incentives and resources

To advance pollinator conservation efforts and their effectiveness, the report highlights the need to increase knowledge and awareness of the socio-ecological benefits of pollinators by integrating social sciences in strategic conservation planning, considering the "common good" framework, conducting thorough stakeholder mapping exercises, and carrying out evaluations of pollinator conservation strategies.

Pollinators offer a flagship opportunity for regional conservation efforts—where meaningful action can be taken at nearly any scale, in virtually any area or community. Within the North American context, as reviewed here, there are many unknowns regarding pollinators, their population trends, and drivers of change. However, it is clear that the ecological, economic and social foundations of life and society in North America are extremely reliant upon pollination and other ecosystem services, which extend across political boundaries.

Acknowledgments

We would like to thank all those who contributed invaluable time, knowledge, and ideas towards this endeavor, including the workshop participants listed below, the members of the CEC project Steering Committee, and the project's consultants.

North American Pollinator Conservation Workshop held in Oaxaca City, Mexico (February 2020)

From Canada: Carolyn Joann Callaghan (Canadian Wildlife Federation), Sheila Colla (York University), Melanie Jacqueline Dubois (Agriculture and Agri-Food Canada), Bryan Gilvesy (ALUS Canada), Jessica Linton (Natural Resource Solutions Inc.), Greg Mitchell, Ilona Naujokaitis-Lewis and Kenneth Tuinigna (Environment and Climate Change Canada – ECCC), Lora Morandin (Pollinator Partnership Canada), Nigel Raine (University of Guelph), and Michel Saint-Germain (Montreal Insectarium – *Insectarium de Montréal)*.

From Mexico: Amando Alvarado Alvarez (Mezcal Ixcateco), Francisco Botello (National Autonomous University of Mexico – *Universidad Nacional Autónoma de México,* UNAM), Wilfrido Cuevas Castro (Corporativo Ñuu Qahwa), Luisa Alejandra Domínguez (National Institute of Ecology and Climate Change – *Instituto Nacional de Ecología y Cambio Climático,* INECC), Nilda Cecilia Elizondo (Special Program for a Healthy and Sustainable Agri-food System), Alejandro Guevara (Iberoamerican University – *Universidad Iberoamericana*), Israel Lorenzo and Sol Ortiz Garcia (Secretariat of Agriculture and Rural Development – *Secretaría de Agricultura y Desarrollo Rural*), Ignacio José March Mifsut (National Commission of Natural Protected Areas – *Comisión Nacional de Áreas Naturales Protegida,* Conanp), María Del Rocío Meneses Ramírez (Paraíso Colibrí), Mauricio Quesada (UNAM – Morelia, Michoacán Campus), Maria Esther Quintero Rivero (National Commission for the Knowledge and Use of Biodiversity, *Comisión Nacional para el Conocimiento y Uso de la Biodiversidad* – Conabio), Oscar Manuel Ramírez Flores (GIZ, Mexico City), Omar Eduardo Rocha Gutierrez (Secretariat of Environment and Natural Resources – *Secretaría de Medio Ambiente y Recursos Naturales,* Semarnat), and Carmen Vasconcelos (MELAPIM, S.P. de R.L.).

From the United States of America: Laurie Davies (Pollinator Partnership), Ryan Drum and Michael Gale (US Fish and Wildlife Service – USFWS), Christina Grozinger (Pennsylvania State University), Jonathan Mawdsley (Association of Fish and Wildlife Agencies), Christine Erika Taliga (US Department of Agriculture, Natural Resources Conservation Service), Jennifer Thieme (Monarch Joint Venture), Mace Vaughan (Xerces Society for Invertebrate Conservation), and Jake Weltzin (US Geological Survey).

Integrating Human Dimensions to Building Collaborative Pollinator Conservation in North America virtual workshop (December 2020)

From Canada: Greg Mitchell and Ilona Naujokaitis-Lewis (Environment and Climate Change Canada – ECCC), Vivian Nguyen (Carleton University), and Maureen G. Reed and James Robson (University of Saskatchewan and UNESCO Co-Chair of Biocultural Diversity, Sustainability, Reconciliation and Renewal).

From Mexico: Maria Esther Quintero Rivero (Conabio), Ana Ortiz-Monasterio (Expert in Environmental Law and Sustainable Development) and María Zorrilla (Iberoamerican University—*Universidad Iberoamericana*).

From the United States of America: Ryan Drum, Katie Steiger-Meister and Natalie Sexton (USFWS).

Project Steering Committee and Consultants

Throughout the project, the CEC Project Steering Committee provided invaluable input: Greg Mitchell and Ilona Naujokaitis-Lewis (ECCC), Ryan Drum (USFWS), Maria Esther Quintero Rivero, Humberto Berlanga, Tania Urquiza, Patricia Koleff, Ana Isabel González and Sylvia Patricia Ruíz (Conabio), Talía Cruz, Eduardo Robelo González, José Eduardo Ponce, José Manuel Juan Diego Monzón, Maria Elena Rodarte, Rodrigo Chavez, Alfonso Prieto and Pablo Domínguez (Conanp), Jorge Alberto Duque, Omar Eduardo Rocha, Carlos Álvarez, Adelita Sanvicente Tello and Cecilia Elizondo (Semarnat) and Luisa Alejandra Domínguez and Isabel María Hernández (INECC).

Consultants Clare E. Aslan (Lead), Taryn Baber, Sara Gabrielson, Hanna Ryder, Martha Sample, Sara Souther, and Sasha Stortz (Landscape Conservation Initiative at Northern Arizona University) and Wynet Smith (Independent consultant) produced the analyses and/or drafted the material that form the core of this document. Consultants from the Landscape Conservation Initiative also facilitated the workshops mentioned above.

1 Overview

Pollinators are animals that help plants produce fruit and seed (Agricultural and Agri-Food Canada 2014). Globally, an estimated 87 percent of 350,000 plant species depend on animals for movement of pollen between plant individuals (Ollerton 2017), including 75 percent of crop species. Thus, pollinators are crucial to the functioning of natural ecosystems, human well-being, and food security. Pollination can be performed by many types of animals, from insects to mammals. Most insect pollinators are in the orders *Lepidoptera, Coleoptera, Hymenoptera, Diptera* and *Hemiptera*. They range from managed honey bees and bumble bees to many solitary native bees, butterflies, flies, ants, wasps and beetles (Aslan et al. 2013, National Research Council 2007). Vertebrate pollinators include birds (such as hummingbirds), bats and other small to midsized mammals, and lizards (Olesen and Valido 2003; Ollerton 2017).

The number of pollinators has declined worldwide due to a combination of factors that include habitat loss and degradation, intensive agricultural management, pathogens, invasive species, climate change and excessive use of agrochemicals, including pesticides (IPBES 2016, Wagner et al. 2021). This decline requires urgent conservation actions and the engagement of stakeholders in different sectors.

In the context of environmental, economic and social linkages between Canada, Mexico and the United States, the CEC "facilitates effective cooperation and public participation to conserve, protect and enhance the North American environment in support of sustainable development for the benefit of present and future generations" (CEC 2023, 3). Pollinators are of high policy priority in North America because of their megadiversity across the continent, their importance for food security and their natural and managed distribution across boundaries. Collaborative efforts involving Canada, Mexico and the United States are needed to identify and address common pollinator challenges and inform effective conservation approaches.

For more than a decade, the CEC has supported trilateral cooperation for the conservation of the monarch butterfly across the continent. Building on this previous work, the Council of the CEC—composed of the highest-level federal environmental authorities from Canada, Mexico and the United States—approved a series of activities on pollinator conservation under the 2019–2020 project, "Strengthening Regional Pollinator Conservation to Secure Local Benefits." The project was overseen by a Steering Committee composed of senior scientists from the three countries and included two multi-stakeholder workshops to guide decision-making on pollinator conservation.

As part of this project, the CEC Secretariat commissioned a state of knowledge on pollinators conservation in North America to inform and advance collaboration on pollinator conservation in the region. Further, the CEC convened two participatory workshops with government representatives and stakeholders from the three countries to identify knowledge gaps and priority areas for collaboration, while bringing attention to the socio-ecological benefits of pollinators and considerations of the human dimension.

The *State of Knowledge on North American Pollinator Conservation: Shared Priorities for the Region* is the culmination of this work. It provides an overview of the status of pollinators in North America (including the results of a quantitative assessment of pollinator observation records from the three countries), summarizes what is known about population trends, provides an overview of drivers of change for population trends and identifies knowledge gaps. It also provides a high-level summary of ecosystem services that pollinators provide in North America and reflections on how social sciences can advance conservation efforts in the region. Finally, it details a set of priority areas for further cooperative work on pollinator conservation in North America and recommendations to better integrate considerations of the human dimension into pollinator conservation efforts.

1.1 Key Messages

- Pollinators provide important ecosystem services and are essential for human well-being and food security. Native bees, butterflies, beetles, ants and flies, and non-insect pollinators such as birds and bats are all valuable crop pollinators that can complement or possibly replace managed pollinators such as bees. However, there is worldwide concern about pollinator declines and recognition of a need to learn more and to act to prevent pollinator decline, including in North America.
- The Commission for Environmental Cooperation has been involved in monarch butterfly conservation for years and has now broadened its focus to other pollinators. Canada, Mexico and the United States have collaborated to develop this publication.

2 Pollinators in North America: Status and Trends

There have been some pollinator assessments in North America, most notably the *Status of Pollinators in North America* by the National Research Council (2007) of the National Academies of the United States, which summarized the role and importance of pollinators, conservation status, causes of pollinator declines, consequences of declines for pollination services, ongoing and required monitoring efforts and strategies for maintaining pollinators and pollination services across the continent. Concern about observed pollinator decline led to the establishment of a United States Pollinator Health Task Force in 2014. In 2015, they published the *National Pollinator Research Action Plan* (Pollinator Health Task Force 2015a) and a *National Strategy to Promote the Health of Honey Bees and Other Pollinators* (Pollinator Health Task Force 2015b). In the same year, the US Department of Agriculture and the US Department of Interior (2015) issued a set of guidelines entitled *Pollinator-Friendly Best Management Practices for Federal Lands*. Mexico published a National Pollinator Strategy (*Estrategia Nacional para la Conservación y Uso Sustentable de los Polinizadores*) in 2021, which includes a synthesis of knowledge and efforts on pollinators in Mexico, identification of knowledge gaps, a summary of pollinator policy, and assessments of the impacts of exotic bees in Mexico. In Canada, Agriculture and Agri-Food Canada published a report in 2014 titled Native Pollinators and Agriculture in Canada detailing the life histories of some of the better-known insect pollinators, their role in agriculture, and some best management practices. Health Canada has also produced several infographics on pollinator conservation in relation to pesticides and bees and best management practices and works with the Organisation for Economic Co-operation and Development to monitor and manage risks to pollinators from pesticides. Currently, various stakeholders led by Academic researchers in Canada are developing a National Pollinator Strategy.

This section provides an overview of the status of pollinators in North America based on a review of existing literature and some highlights of the results of an assessment of existing observation records (see Box 1 for a brief overview of the methods and Appendix 1 for a more detailed discussion).

2.1 Pollinator Diversity

In North America, pollinators include a wide range of species, native and non-native, wild and managed. There are limited-range species and others that migrate across the continent's national borders, (for example, the monarch butterfly or certain bat species). Overall, the continent exhibits markedly high numbers of several key pollinator groups (for example, solitary bees, hummingbirds and ants). However, baseline information on native pollinator populations in North America as a whole is quite sparse (National Research Council 2007) and wild pollinator diversity is still only partially understood. Knowledge gaps stemming from under-sampling of remote regions and cryptic taxonomic groups persist. Since knowledge of insect diversity is limited, with large numbers of species yet to be described (National Research Council 2007), assessments of pollinator taxonomic diversity are limited to those species that have been examined, along with extrapolations based on habitat extent and diversity among better-studied species.

As part of the work undertaken for this publication, researchers from University of Northern Arizona developed a database of assumed pollinator genera based on published literature and then retrieved observation records of those genera from the Global Biodiversity Information Facility, an international repository for species occurrence data (see Box 1 and Appendix 1 for more details).

Box 1. Overview of the Quantitative Assessment

The researchers developed a database of assumed pollinator genera based on published literature and then retrieved observation records of those genera from the Global Biodiversity Information Facility (GBIF). They used existing overviews of pollination in North America to assemble the genus list and developed a records extraction code using R version 3.6.2 (https://cran.r-project.org/) to extract data on pollinator genera from GBIF. They extracted data on the spatial distribution, number of observations, observation time horizon and species within a genus. They also used georeferenced data points to extract information on ecoregion and habitat type from the Ecoregions of North America Level 1 (CEC 1997) and from the North American Land Change Monitoring System Landsat 30-meter data layers (CEC 2015). These location data allowed an examination of relative distributions of pollinator occurrences in order to identify ecoregions and habitats with particularly high pollinator diversity.

A similar method was used for vertebrate pollinators, with a list of 228 known vertebrate nectar-feeders in North America taken from Aslan et al. (2013) and entered at the species level into the GBIF query system. They used the query code to extract observation number and frequency, spatial distribution, observation time horizon, ecoregion and habitat type for the full list of vertebrates. They also used the International Union for the Conservation of Nature (IUCN) Red List, version 3, to extract conservation status for all vertebrates in the database.

Although the IUCN Red List is far less developed for invertebrates than for vertebrates, they also downloaded the conservation status for all invertebrates in the database. However, because few invertebrates have been evaluated, the researchers also examined national and state/province-level conservation assessments to identify other pollinator species of conservation concern. The researchers then applied the GBIF query code to each species of concern to obtain its observation number and frequency, spatial distribution, ecoregion and habitat type.

In combination, these methods generated the number of records per taxon, including those of conservation concern, per geographic area, allowing an examination of the known diversity by taxonomic group and conservation status across the continent. The query coding allowed the researchers to determine which ecoregions and habitat types appear to support recorded diversities that were particularly high and which contain particularly high concentrations of threatened pollinator diversity. Importantly, these methods provide a quantitative overview of pollinator occurrence based on an immense dataset of robust records assembled with rigorous quality control and including taxa that are rare or absent in peer-reviewed literature. In combination with a literature overview of pollinator trends, the approach provides insights into the state of pollinators of North America and allows a discussion of the relevance of current pollinator declines for ecosystem services, biodiversity, socio-cultural values and agriculture.

For full methodological notes, please consult Appendix 1.

Source: University of Northern Arizona Landscape Conservation Initiative, 2021

The database included 2,839 insect pollinator genera for North America: 1,353 genera of *Diptera* (two-winged or true flies), 1,207 genera of *Lepidoptera* (butterflies, moths and skippers), 162 genera of Hymenoptera (ants, bees, ichneumons, chalcids, sawflies and wasps), 106 genera of *Coleoptera* (beetles and weevils) and 11 genera of *Hemiptera* (true bugs: cicadas, aphids, planthoppers and leafhoppers among others) (see table provided in Appendix 2). The most species-rich genus in the database is the bee *Andrena*, with 506 species occurring across the three countries. Of the 2,839 insect genera identified in total, 2,592 have been recorded in the United States, 1,645 have been recorded in Canada, and 1,082 have been recorded in Mexico.

Extracted GBIF records for these genera correspond to 24,184 species representing 1,807,491 separate observations across the three countries. The extracted GBIF data identified 7,860 pollinator species across Canada, belonging to mainly to the *Diptera* (916 genera), *Lepidoptera* (618 genera), *Coleoptera* (55 genera) and *Hymenoptera* (47 genera). Among the 916 genera of *Diptera* identified, the majority (161 genera) are *Tachinidae* (true flies), followed by, *Chironomidae* (informally known as chironomids, nonbiting midges, or lake flies – with 82 genera), *Syrphidae* (hover flies, with 55 genera), and *Chloropidae* (commonly known as frit flies or grass flies, with 41 genera). Among *Lepidoptera*, the *Noctuidae* (commonly known as owlet moths, cutworms or armyworms), have the most genera, at 212.

The GBIF contained records for 19,552 pollinator species in the United States. As in Canada, the highest number of genera belong to the order *Diptera* (1,244 genera). The records also include 1,164 genera of *Lepidoptera* and 101 genera of *Hymenoptera*. Within the *Lepidoptera*, there are 358 genera of *Noctuidae*, 230 genera of *Geometridae* (geometer moths), and 200 genera of *Crambidae* (grass moth family). Among *Diptera*, there are 183 genera of *Tachinidae* and 125 genera of *Chironomidae*.

The GBIF contained records for 5,314 pollinator species in Mexico. Analysis of the records reveals 628 genera of *Lepidoptera*, 275 genera of *Diptera* and 129 genera of *Hymenoptera*. The *Lepidoptera* family *Noctuidae* is particularly well-represented, with 117 genera.

Identification of all pollinators in North America is not feasible, so there may be cryptic, rare, or undetected pollinators or pollinator groups that were not included in the database of assumed pollinators used to extract records from the GBIF. Many pollinators are exceedingly difficult to detect, catch and identify, making even the extensive database of the GBIF sparse for many taxonomic groups and biased toward more charismatic or visible taxa. It is important to note that GBIF records indicate where taxa have been observed and recorded—that is, records indicate presence but not absence of likely pollinators. Moreover, the continent is unevenly sampled. Locations that are remote, topographically complex, far from human settlements, or perceived as dangerous rarely receive the sampling intensity of locations that are easily accessible, meaning that the results are not necessarily a reflection of the relative number of species present in each country, ecosystem and habitat type. However, the analysis does provide a state of knowledge, including data on taxonomic groups and locations, while recognizing that the true diversity of pollinators in any location is unknown, and that continued research will reveal new areas and species of importance. It can also be used to infer knowledge gaps and areas of under-sampling.

A brief survey of published literature highlights some of the variability of pollinators in North America. For example, there are 4,337 known native bee species in North America and Hawaii (Kopec and Burd 2017), with 4,000 in the United States alone (Kopec and Burd 2017, Moisset and Buchmann 2011) while Canada has more than 900 native bee species (Agriculture and AgriFood Canada 2014). The diversity of wild bees in Mexico is unknown, due to current sampling and knowledge gaps; however, it has been estimated at over 1,800 species (Freitas et al. 2009)

There are numerous species of *Lepidoptera* in North America. According to the Smithsonian Institute, there are nearly 11,000 species of moths (Smithsonian n.d.b) and approximately 750 species of butterflies in the United States (Smithsonian n.d.a). Pohl et al (2018; see also Pohl et al 2019) report that a total of 5,405 species of moths and butterflies belonging to 81 families are known to occur in Canada, with an additional 50 species reported but not confirmed. Most of these species are moths while 306 species belonging to six families are butterflies; 207 of reported species are non-native (Pohl et al. 2019). An earlier report (Hall 2009) reported there are at least 300 species of butterflies in Canada, of which five are endemic.

Among bird pollinators in North America, major families include *Trochilidae* (hummingbirds) with 109 species, *Icteridae* (New World blackbirds) with 23 species, *Thraupidae* (tanagers) with 13 species, *Fringillidae* (true finches) with 11 species, *Cardinalidae* (cardinals) with 9 species and *Parulidae* (New World warblers, sometimes called wood-warblers) with 9 species. Mammalian pollinators include 16 nectar-feeding species of *Phyllostomidae* (New World leaf-nosed bats). Three of these species are found in the United States while 12 species are found in Mexico, with all exhibiting limited ranges (Arita and Santos-del-Prado 1999; confer National Research Council 2007). Three of the bats are long-distance migratory species, including the lesser long-nosed bat (*Leptonycteris curasoae*), the hog-nosed bat (*Choeronycteris mexicana*) and the Mexican long-nosed bat (*Leptonycteris nivalis*) (National Research Council 2007).

2.2 Pollinator Diversity by Ecoregion and Habitat

There is an immense diversity of pollinator habitat types in Canada, Mexico and the United States. All major terrestrial biomes occur on the continent, including tropical-subtropical forests, temperate-boreal forests and woodlands, shrublands and shrubby woodlands, savannas and grasslands deserts, semi-deserts and polar-alpine. Elevations range from 86 meters below sea level to 6,190 meters.

According to the data extracted by the researchers from GBIF, pollinators are found across all 15 North American ecoregions. In Canada, a high number of occurrences are found in the Eastern Temperate Forests (837 genera) and Northern Forest (215 genera), with fewer occurrences in Taiga (22 genera) and Tundra (11 genera) ecoregions. Canadian habitat types with the highest genus occurrence in the database include agricultural and urban areas, as well as barren lands, with 381 genera in urban and built-up areas and 256 genera in cropland, likely an artifact of human activity and thus heavy sampling effort.

For the United States, particularly highly recorded occurrences are in the Eastern Temperate Forests (798 genera) and Great Plains (499 genera), as well as in the Mediterranean California (310 genera) and North American deserts (227 genera) ecoregions. Few occurrences have been recorded in the Taiga (36 genera), Tundra (41 genera), and Temperate Sierras (56 genera) ecoregions. The arid ecoregions of the southwestern United States contain a high diversity of native bees. The highest relativized occurrences of pollinator generic diversity in the United States occurs in tropical broadleaf evergreen forest, followed by wetlands, tropical or subtropical shrubland, and tropical or subtropical grasslands. As in Canada, genera recorded in the United States are concentrated in urban areas, with high occurrence as well as in higher latitude temperate needleleaf forests, tropical or subtropical shrublands, and wetlands. Needleleaf forests are generally more arid but also easier to sample than broadleaf forests, and account for wide swaths of the west and north of the United States.

In Mexico, particularly highly recorded occurrences come from the Temperate Sierras (348 genera) and Tropical Dry Forests (295 genera) ecoregions. These ecoregions are located in the northwest and central sections of the country, in regions topographically diverse and largely arid. Together, this suggests that warm zones high in productivity and arid regions diverse in elevation are sources in Mexico of high generic diversity. By habitat type, highly recorded occurrences are also clustered in croplands and urban and built-up areas, followed by tropical or subtropical broadleaf deciduous forest and tropical or subtropical shrublands. However, as noted earlier, areas with high occurrence of records likely show biased survey effort. Although Mexico includes both humid and dry tropical forests and spans an enormous diversity of habitat types and topography, the total number of genera recorded in the country is considerably less than that recorded in the United States. Yet important pollinator groups such as *Lepidoptera* and *Diptera* are known to increase in diversity in the tropics, suggesting that these groups and others are likely undersampled in southern Mexico.

Plant dependence on animal pollination is highest in tropical and desert sites, and lowest in tundra, taiga, grasslands, and conifer-dominated ecosystems, where dominant plant species are wind-pollinated (Regal 1982). Wet and dry tropical systems exhibit high pollinator diversity spanning functional groups, including *Phyllostomidae* (nectar-feeding bats), *Trochilidae* (hummingbirds), *Hymenoptera* (bees and others), *Diptera* (flies), *Lepidoptera* (butterflies and moths), and *Coleoptera* (beetles). Deserts and arid shrublands are centers of diversity for native bees, which are exceptionally efficient pollinators (Michener 2000). A high diversity of plants across both warm and cool deserts dominated by cacti, legumes, and sagebrush rely on pollinators (Buchmann and Nabhan 2012, Love and Cane 2019). As noted, the highest recorded diversity of pollinator genera in Canada and the United States occurs in the eastern deciduous forests of Quebec, Ontario, and the United States east of the Mississippi. These forests receive abundant rainfall and experience lengthy warm growing seasons and high primary productivity, conditions that may give rise to pollinator diversity. However, the human population is also notably high across the same region, possibly resulting in observational bias.

2.3 Managed and Introduced Species

In North America, a handful of pollinator species are actively managed, that is, they are semi-domesticated, produced in large quantities and bought and sold commercially (National Research Council 2007). Most of these are introduced or exotic species although some are native. Managed pollinators are a reflection of the importance of the ecosystem services that pollinators provide and agricultural communities invest considerable resources in their services.

The most common managed pollinator species in North America is the European honey bee (*Apis mellifera*), which is present in both actively husbanded hives and in feral colonies across the continent. Most honey bee colonies across Mexico and the southern United States are now Africanized, containing at least some genes from *A. mellifera scutellata*, a subspecies introduced to Brazil from Africa in the 1950s in order to boost honey bee colony productivity (Kadri et al. 2016). Africanized honey bee colonies grow and reproduce more quickly than European honey bee colonies and can be more aggressive and difficult to manage, depending on the proportion of colony genes that are Africanized.

The European honey bee (*A. mellifera*) is both the most widespread exotic species and the most abundant managed pollinator in all three countries. With about 2 million bee colonies managed by 41,000 commercial producers, Mexico has one of the world's largest honey industries (Nieto 2011), with Yucatán, Campeche, and Jalisco being the leading honey-producing states (Contreras-Escareño et al. 2016). In the United States, feral honey bees have naturalized in all ecosystem types and managed hives are located in all regions of the country. The US Department of Agriculture (2021a) estimates that there are 2.66 million managed honey bee colonies, down from a high of 4 million in the 1940s. As for Canada, the Canadian Honey Council (2018) estimates that a total of 773,000 colonies of honey bees are managed by nearly 10,000 beekeepers. Beekeeping is most common in the provinces of Alberta, Saskatchewan and Manitoba, which have about 533,000 colonies and produce 79 percent of Canadian honey (Canadian Honey Council 2018).

Bumble bees have been introduced across the world as alternative pollinators (National Research Council 2007). For example, *Bombus terrestris*, introduced from Europe primarily for greenhouse tomato pollination, can be found across North America (Winter et al. 2006). In Canada, bumble bees are used for pollination of 25 crops, particularly greenhouse tomatoes and peppers (Canadian Food Inspection Agency 2013b).

The European alfalfa leafcutting bee (*Megachile rotundata*) is now also abundant across Canada and is an important managed pollinator of industrial agriculture in the country. It is used to pollinate alfalfa seed fields in Alberta, Saskatchewan, and Manitoba and provides approximately half of the pollination required for hybrid canola seed production, as well as other legume seed crops and lowbush blueberries (Canadian Food Inspection Agency 2013a). Alfalfa leafcutting bees can boost alfalfa seed yields twentyfold, but must be introduced in very high densities to alfalfa fields, requiring intensive farm labor to construct and move their nesting resources (Richards and Kevan 2002). The species has also been introduced to the United States as a pollinator for alfalfa, carrots, and other crops. A solitary bee, it does not form large colonies but is brought into agricultural areas by farmers (National Research Council 2007). The solitary, horned mason bee (*Osmia cornifrons*) was introduced to the United States from Asia as a pollinator for apples (Hedtke et al. 2015).

Other common documented non-native bee species in the United States include several introduced *Hylaeus* spp. bees, *Andrena wilkella, Halictus tectus*, various *Lasioglossum* spp., several species from the families *Megachilidae* and *Apidae*, most of which were accidentally introduced and likely transported to the United States on plant materials (Russo 2016). In Canada, other documented introduced bees include *Hylaeus* spp., *Andrena wilkella*, *Lasioglossum* spp., *Anthidium* spp., *Chelostoma* spp., *Hoplitis anthocopoides*, *Osmia caerulescens*, and *Megachile* spp. (Sheffield et al. 2011).

Beyond bees, known non-native pollinators in the United States include flies, such as the cosmopolitan house fly *Musca domestica*, the cabbage white butterfly (*Pieris rapae*), and various moths including nondescript micro-lepidopterans. As the coldest and most northerly country in North America, Canada has a smaller diversity of exotic established species than the other two countries, but its large agricultural areas have been colonized by various Eurasian species. For example, over 200 non-native moth species are known to be established in Canada (Pohl et al. 2019); other non-native species include muscid flies and other *Diptera*, beetles, and true bugs, many of which can be occasional or incidental pollinators (Langor et al. 2014). Other non-native pollinators in Mexico include various introduced flies, moths, and butterflies (Suckling et al. 2017). New detections of non-native pollinators are likely as global patterns of trade continue and as detection pathways such as community science and DNA barcoding are increasingly filling knowledge gaps (Encarnação et al. 2021, Jinbo et al. 2011, Larson et al. 2020).

Some native species are also managed. For example, Melipona stingless bees have been managed for their honey and wax production in Mexico since Mayan times. The state of Yucatán is the center of Melipona honey production in Mexico, and the most ancient known beekeeping techniques in Yucatán involve the cultivation, maintenance, and management of *Melipona beecheii* colonies in hollow logs (Villanueva-Gutiérrez et al. 2005). Melipona honey is produced in smaller quantities, from smaller colonies, but is considered more exotic and desirable in flavor than *A. mellifera* honey and therefore sells at a higher price. As a native species, Melipona stingless bees are raised using traditional methods and native forage plants and therefore represent an alternative to *A. mellifera* in light of competition and disease transmission concerns.

Easy to rear, transport, and track, native bumble bees, including *B. impatiens* and *B. occidentalis*, have been managed in the United States since the late 20th century, again primarily for use in greenhouse pollination (Velthuis 2002); there is research into use of regionally-specific, native bumble bee species for tomato production in greenhouses (Strange 2015). In the United States, notable agricultural successes include providing habitat for diverse native bee communities, and particularly mason bees (*Osmia* spp.), to bolster the success of fruit setting in blueberries (Isaacs and Kirk 2010, Stubbs et al. 1997), as well as increasing strawberry production by supplementing existing *O. lignaria* populations near focal fields (Horth and Campbell 2018). The native *Nomia melanderi*, a ground-nesting bee, is managed for alfalfa pollination, with farmers creating underground nests with saline soil amendments (National Research Council 2007). Native North American orchard mason bees (*Osmia lignaria*) are managed in southern Canada for pollination of apples and other orchard fruits (Richards and Kevan 2002); their nests can be easily moved from site to site and their introduction in relatively low densities leads to increased fruit yields.

2.4 Pollinator Population Trends

Globally, there is increasing concern that a pollinator crisis is emerging, with population sizes and pollinator diversity in decline and pollination as an ecological function at risk. This is evident in the report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES 2016). Subsequent studies have reported alarming declines in insect populations around the world, across taxonomic groups, geographic regions, and habitat types (Hallmann et al. 2017, Leather 2018, Wagner 2017, 2020). As much as 40 percent of insect species are threatened with extinction (van Klink et al. 2020) and two major pollinator groups (*Hymenoptera* and *Lepidoptera*) are at particular risk (Sánchez-Bayo and Wyckhuys 2019). Records are too sparse to assess global declines for most groups of flies, micromoths, beetles and other inconspicuous pollinators, but three decades of insect collecting in hundreds of western European nature reserves have revealed precipitous declines across taxonomic groups in recent years (Vogel 2017). There is concern both about wild species from a conservation perspective and about managed species and impacts on agriculture (National Research Council 2007). Global declines in honey bee populations and losses of managed hives have raised alarms among agricultural industries in countries worldwide (Paudel et al. 2015). A recent analysis based on IUCN Red List classifications found that 15.6 percent of 1,162 vertebrate pollinators worldwide are currently threatened with extinction (Aslan et al. 2013).

The quantitative assessment for North America conducted by the researchers identified 1,159 species of concern listed in international (59 species), national (35 species), or state/provincial (1,065 species) sources. Vertebrate species of concern include four bats and seven hummingbirds, all ranked as Near Threatened, Vulnerable, Endangered or Critically Endangered by the IUCN (Table 1). Among insects, 78.4 percent of the species of concern are *Lepidoptera* (butterflies and moths), 13.4 percent are *Hymenoptera* (bees, wasps and ants), 4.3 percent are *Diptera* (flies) and 3.9 percent are *Coleoptera* (beetles). However, *Lepidoptera* are more easily detected and identified than the other insect groups and it is likely that records of their occurrence and decline are therefore more complete. As studies of non-lepidopteran pollinators continue to expand across the continent, it can be expected that data indicating decline in more cryptic species will become more available and more species will be added to these lists.

Observation records retrieved from the Global Biodiversity Information Facility (GBIF) show that 716 of the identified species of concern occur in Canada, 201 are known to occur in Mexico and 1,088 occur in the United States. Ecoregions with the highest occurrence of species of concern include: Eastern Temperate Forests (269 species), Northern Forests (151 species) and Great Plains (100 species), in Canada; Eastern Temperate Forests and Great Plains, in the United States, and Temperate Sierras and Tropical Dry Forests, in Mexico.

Table 1. Vertebrate Pollinators Identified as Species of Concern on IUCN Red List

Class	Family	Species	Threat Status	Countries
Mammalia	*Phyllostomidae*	*Choeronycteris mexicana* (Mexican long-tongued bat)	Near Threatened	Mexico, United States
	Phyllostomidae	*Leptonycteris nivalis* (Greater long-nosed bat)	Endangered	Mexico, United States
	Phyllostomidae	*Leptonycteris yerbabuenae* (Lesser long-nosed bat)	Near Threatened	Mexico, United States
	Phyllostomidae	*Musonycteris harrisoni* (Banana bat)	Vulnerable	Mexico
Aves	*Trochilidae*	*Cynanthus lawrencei* (Broad-billed hummingbird)	Near Threatened	Mexico
	Trochilidae	*Doricha eliza* (Mexican sheartail)	Near Threatened	Mexico
	Trochilidae	*Eupherusa cyanophrys* (Oaxaca hummingbird)	Endangered	Mexico
	Trochilidae	*Eupherusa poliocerca* (White-tailed hummingbird)	Vulnerable	Mexico
	Trochilidae	*Eupherusa ridgwayi* (Mexican woodnymph)	Vulnerable	Mexico
	Trochilidae	*Lophornis brachylophus* (Short-crested coquette)	Critically Endangered	Mexico
	Trochilidae	*Selasphorus rufus* (Rufous hummingbird)	Near Threatened	Canada, Mexico United States

Source: IUCN.

While there are generally limited data with respect to pollinator population trends in North America (National Research Council 2007), critical declines have been recorded for a few well-studied species, including wild and managed species. Although not strictly a conservation issue, declines in *A. mellifera* numbers in some regions have concerned beekeepers for decades (for example, Dicks et al. 2021, National Research Council 2007). The number of honey bee hives in the United States declined by nearly 50 percent between the 1940s and 2015 (Pollinator Health Task Force 2015b). Overwintering colony losses reported by beekeepers between 2006 and 2015 averaged 31 percent, twice the economically sustainable level (Pollinator Health Task Force 2015b), and these pulses of increased colony collapse disorder, wherein full hives die at a high rate, spanned the United States (Johnson and Steiner 2000). Beekeepers in the United States lost 45.5 percent of their managed honey bee colonies between April 2020 and April 2021, according to preliminary results of the 15th annual nationwide survey conducted by Bee Informed Partnership (BIP), marking the second-highest loss rate since the survey began in 2006 (University of Maryland 2021). In Canada, mortality in *A. mellifera* colonies has increased dramatically in recent decades. For example, Ontario reported losses of 46 percent of colonies over winter in 2017–2018 (Ontario Ministry of Agriculture, Food, and Rural Affairs 2018). In general, beekeeping in Canada has declined over recent decades and there are only 16 percent as many beekeepers as in 1945 (Melhim et al. 2010).

Little is known about trends for populations of non-managed bees that comprise the majority of pollinators (Lebuhn et al. 2013, Winfree et al. 2011). However, population declines in the United States have been documented for some populations of non-managed bee pollinators. A resurvey of an Illinois pollination network found that 50 percent of bee species have disappeared over 120 years (Burkle et al. 2013). In another study, museum specimens of wild bee species in northeastern North America were examined. Although historical records are sparse and identification is difficult, approximately 50 percent of the species studied were found to have had significant elevational or latitudinal shifts, with evidence of population decline for 14 species, while eight species demonstrated population increases, emphasizing variability in vulnerability among taxa (Mathiasson and Rehan 2019). In a spatial analysis of wild bee populations, parameterized using expert abundance assessments and land cover databases, modeled wild bee abundance declined across 23 percent of the land area of the United States from 2008 to 2013 (Koh et al. 2016).

Bumble bees are particularly well recorded among native bee taxa due to their size and ease of identification. A comparison of historic records and contemporary data demonstrates that nearly half of bumble bee species studied in North America show some evidence of decline (Colla et al. 2012). Another analysis of museum specimens and directed bumble bee surveys found that four species exhibited substantial relative population declines (up to 96 percent) and estimated range contractions of 23 to 87 percent (Cameron et al. 2011); there is evidence of decline of the two-formed bumble bee (*Bombus bifarius*) (Cameron et al. 2011, Spivak et al. 2011). In Canada the rusty-patched bumble bee (*Bombus affinis*) and the Gypsy Cuckoo Bumble Bee (*Bombus bohemicus*) are currently designated as endangered under Canada's Species at Risk Act, and the American Bumble Bee (*Bombus pensylvanicus*), Suckley's Cuckoo Bumble Bee (*Bombus suckleyi*), the western Bumble Bee *mckayi* subspecies (*Bombus occidentalis mckayi*), the western Bumble Bee *occidentalis* subspecies (*Bombus occidentalis occidentalis*), and the yellow-banded bumble bee (*Bombus terricola*) being considered for listing under various threat status levels under the Act. In 2017, the rusty patched bumble bee was listed as endangered under the US Endangered Species Act by the US Fish and Wildlife Service, driven by population losses of 91 percent over two decades (Lambe 2018). This was the first bee of the United States mainland to be added to the list, although seven Hawaiian *Hylaeus* bees had been listed the previous year.

There is also evidence of decline in some species of butterflies and moths. The monarch butterfly (*Danaus plexippus*) displays high fidelity to their wintering grounds as well as high concentrations within those grounds, allowing accurate year-to-year population counts (Thogmartin et al. 2017). The species has displayed precipitous population decline, with losses of up to 84 percent in the two decades since 1996 (Semmens et al. 2016). In Ohio, over 21 years of monitoring indicated butterfly abundance dropped 33 percent, paralleling declines observed in Europe (Wepprich et al. 2019). Furthermore, although specialized and rare species exhibit particularly marked declines (Thomas 2016), even common generalist species demonstrate population losses, suggesting that the various stressors confronting butterfly populations create multiple pathways of change (Wepprich et al. 2019). Community science surveys performed between 1992 and 2010 demonstrated northward range shifts for most butterfly species in Massachusetts, with range contractions for several species (Breed et al. 2013). Due to their conspicuous, charismatic appeal and ease of identification, butterflies are better studied than most insect groups; declines observed in these taxa may also be occurring across a broad swath of insect groups without notice (Thomas 2016).

Anecdotal reports by moth collectors in the northeastern United States indicate broad reductions in moth populations over recent decades, with particular declines among large-bodied species (Wagner 2012), which reflects findings in longer-monitored populations in Europe (Fox 2013). Historic museum collections of hawkmoths (*Sphingidae*) for the same region of the United States found population declines spanning over a century, for eight of the 22 species with sufficient data, whereas four species increased during the same time period (Young et al. 2017). Macro moth abundance and diversity at organic soybean farms was found to be significantly higher than in conventional farms in eastern Ontario, indicating the importance of human practices and drivers of change (Put et al. 2018).

The order *Diptera* is very diverse and, as noted, 124 families and 24,210 species have been found in Canada, Mexico and the continental United States (Thompson 2006 in National Research Council 2007). However, there are very few studies of flies and knowledge of the distribution and population sizes of flies in North America is virtually non-existent; the number of pollinators is unknown and population trends cannot be determined for known pollinator species (National Research Council 2007).

Among vertebrates, the best-studied North American pollinators are hummingbirds and more than 14 percent of hummingbird species in the Americas are at risk of extinction, with particular concentration in southern Mexico (Wethington and Finley 2008). As of 2007, there was limited population data for pollinating bats (National Research Council 2007) despite the fact pollinating bats "provide important services for many species of North American plants," such as columnar cacti and *Agave* species.

2.5 Summary and Knowledge Gaps

Rich diversity of pollinator species has been present across North America, but the current extent of that diversity and its population trends are still unknown, although some orders, families and genera are better documented than others. Knowledge about population trends for most insects is lacking as they are notoriously hard to study and a lack of baseline data makes it difficult to develop quantitative population estimates (Colla et al. 2012). Knowledge gaps stemming from under-sampling of remote regions and cryptic taxonomic groups persist, and long-term studies that would enable broader understanding of population trends and drivers of change are lacking; hence the need to extend population assessments and analyses geographically and taxonomically (Didham et al. 2020, Montgomery et al. 2020, Simmons et al. 2019).

Sampling effort is an important consideration when interpreting the results of the quantitative assessment of GBIF records. Urban and built-up areas emerged as important land cover for available data based on GBIF records in each country, emphasizing the tendency for people to collect and record species they encounter in the locations they frequent, rather than true maximum diversity in such sites. Although bees are known to exhibit highest diversity in arid regions (Michener 2000), other pollinators likely peak in diversity in the tropics, as do many other taxonomic groups. The general dearth of detections in tropical habitats, as well as fewer detections in Mexico than in Canada, certainly stems from unequal sampling across the three countries and across all habitat types, rather than actual lower pollinator richness. A lack of consistent sampling across the continent is a major knowledge gap that leads to underestimation of pollinator diversity in some regions and points to a need to expand sampling beyond human-dominated land covers.

Pollinator communities are in constant flux across the North American continent as wild pollinator populations fluctuate in response to annual climate and global change, such as trade relationships. It is possible that several exotic pollinators have been introduced, either intentionally or accidentally, that are not captured in this report, and it is possible that these exotic species have gone undetected for long periods of time. Current lists of both native and non-native pollinators are incomplete for the three countries and the implications of changes in pollinator communities for pollination of crops and wild plants are little understood. An increasing amount of research examines the effectiveness of pollinators other than honey bees in crop pollination (e.g., native bees), but management of wild pollinator communities remains relatively underexplored across agricultural communities.

Understanding the habitats and regions where pollinator communities are least understood is also important for appropriate management and conservation across the region. For example, in forested habitats, pollinators tend to require gaps in the tree canopy and shrub layers, where light can facilitate growth of flowering understory plants such as forbs (Hanula et al. 2016). Overgrown woody layers, a consequence of changes, such as fire suppression, can reduce occurrence of pollinator-friendly habitat in forested landscapes. Managing forests for pollinators may include the creation of light penetration gaps or planting of pollinator forage species along right-of-ways (Hanula et al. 2016).

2.6 Key Messages

- Pollinators include both native and non-native species and can be either wild or managed. Most pollinators in North America are insects, ranging from bees, wasps and butterflies to flies and beetles. A quantitative assessment identified over 24,000 species of insect pollinators belonging to 2,829 genera in Canada, Mexico and the United States. Of these insect genera, 2,592 have been recorded in the United States, 1,645 have been recorded in Canada, and 1,082 have been recorded in Mexico. There are also some bird (hummingbirds) and bat pollinators, although the latter are found only in Mexico and the United States. While the number of recorded species in Mexico is lower than in Canada and the United States, this is likely an artefact of observational bias.
- Pollinators are found throughout North America, although there are more species recorded in some ecoregions, such as Eastern Temperate Forests in both Canada and the United States and Temperate Sierras and Tropical Dry Forests of Mexico. Geographic locations are

unevenly sampled across the continent and locations that are remote, topographically complex, far from human occupancy, or perceived as dangerous rarely receive the sampling intensity of locations that are easily accessible. An absence from a particular ecoregion or habitat, therefore, can be interpreted only as a lack of confirmed presence, rather than a true absence. The taxonomic lists produced here will thus incorporate this uncertainty.

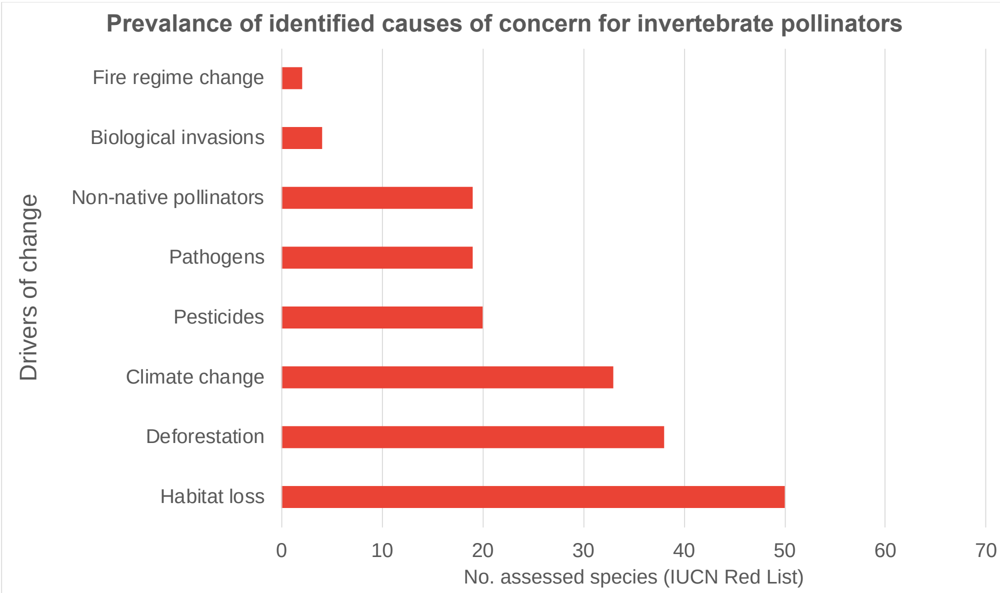
- In North America, only a few pollinator species are actively managed—that is, they are semi-domesticated, produced in large quantities, and bought and sold commercially. Most of these are introduced or exotic species although some are native. Honey bees are the most used and well known, but other managed pollinators include mason bees, some bumble bee species, and alfalfa leafcutting bees. North America also has a number of other invasive species that can be pollinators, including the cosmopolitan house fly and the cabbage white butterfly, as well as various moths, beetles and true bugs. Native insects are also important pollinators for agriculture and some are actively managed, including some native bumble bee species.
- The quantitative assessment for North America identified 1,159 species of concern listed in international (59 species), national (35 species), or state/provincial (1,065 species) sources. Vertebrates of concern include four bats and seven hummingbirds, all ranked as Near Threatened, Vulnerable, Endangered, or Critically Endangered by the IUCN. In terms of insect pollinators, 78.4 percent of the species of concern are *Lepidoptera* (butterflies and moths), 13.4 percent are *Hymenoptera* (bees, wasps and ants), 4.3 percent are *Diptera* (flies) and 3.9 percent are *Coleoptera* (beetles).
- The species of concern include 716 that occur in Canada, 201 in Mexico and 1,088 in the United States. Ecoregions with the highest occurrence of species of concern in Canada include Eastern Temperate Forests, Northern Forests and the Great Plains. Ecoregions with highest occurrence of species of concern in the United States include the Eastern Temperate Forests and Great Plains while Mexico's ecoregions with highest occurrence of species of concern are the Temperate Sierras and Tropical Dry Forests.
- While there is generally limited data with respect to pollinator population trends in North America, critical declines have been recorded for a few well-studied species, including wild native and managed species. Some species of butterflies, moths and bees have experienced population declines, while a few have had increases. Some hummingbird species are also species of concern. There is insufficient data on nectar-feeding bats to identify population trends.

3 Drivers of Change

Global studies of drivers of change behind pollinator declines have identified a suite of causes contributing to trends that threaten biodiversity in all ecosystem types and geographic regions (Janzen and Hallwachs 2019, Sanchez-Bayo and Wyckhuys 2019, Wagner 2020). Pollinators face a wide range of emerging and increasing drivers of change, including habitat loss and fragmentation; pesticide exposure; spread of disease and parasites; pollution of soils, air, and waterways; introduction of non-native competitors and predators; direct exploitation; and climate change (Gill et al. 2016, Potts et al. 2010, Vanbergen and the Insects Pollinator Initiative 2013). Drivers act both independently and synergistically (Brook et al. 2008a) and pollinator population dynamics in response to these interacting factors can be complex and difficult to predict.

The IUCN lists causes of conservation concern for the species it evaluates. For North American invertebrates included on the IUCN Red List (limited to 70 evaluated species), the most commonly listed cause is general habitat loss, followed by deforestation and climate change (Figure 1).

Figure 1. Identified Causes of Concern for Invertebrate Pollinator Species



Source: Derived from IUCN Red List

This section reviews what existing studies identify as drivers of change for various pollinators in North America

3.1 Habitat Loss/Fragmentation/Land Use

The most widespread and impactful driver of change for North American pollinators is habitat loss stemming from land-use change. In the United States, non-*Apis* bees, butterflies, bats and other managed or wild pollinators are impacted by habitat loss and degradation; there is also strong evidence that, for some species, habitat loss has led to population declines (National Research Council 2007, Potts et al. 2010). In the earlier referenced study that found wild bees had declined across 23 percent of the land area of the United States, abundance declines were particularly pronounced in locations with greater occurrence of pollinator-dependent crops, in part due to transformation of natural habitat to row-cropping (Koh et al. 2016). Similarly, in tropical forests in Mexico, habitat fragmentation has been shown to reduce the total abundance of pollinators (Aguirre and Dirzo 2008). Particularly susceptible pollinator species likely include specialists with unique forage or nesting requirements, since transformed ecosystems may lose those critical resources (Potts et al. 2010). For example, a study of habitat fragmentation in the Sonoran Desert found that decreasing fragment size was related to decreasing occurrence of specialist bee species, although generalist species seemed unaffected by habitat fragmentation (Cane et al. 2006).

Habitat loss is identified as a critical driver of bat population losses, and human disturbance and development of caves has likely removed important roosting and maternal sites for bats in many areas. Bats are large and mobile and may therefore connect habitats across areas of disturbance or fragmented landscapes, potentially making them an important source of plant gene flow in the face of regional environmental changes (Herrerias-Diego et al. 2006).

As the continent becomes increasingly developed and connected, construction of new transportation corridors and large land-area solar and wind farms intersect pollinator habitats. Although rarely discussed as a major threat in comparison to habitat loss owing to agriculture and urban sprawl, climate change, pesticides, and disease, an extrapolative study of road mortality found that billions of pollinating insects may be killed by vehicle traffic each year (Baxter-Gilbert et al. 2015). Collisions are particularly likely on high-speed transportation corridors.

Road construction also disturbs road verges and these tend to be hotspots for colonization of invasive plant species. Roadside restoration efforts aim to plant native species, in order to avoid these invasions, and often target pollinator-friendly species in order to bolster pollinator habitat across a region (Wojcik and Buchmann 2012). For example, in the United States and Canada, over 200 organizations are involved with the Rights-of-Way as Habitat Working Group, collaborating across gas, electric, rail, and road industries to restore habitat. However, there is evidence that roadside habitat supporting and attracting pollinators may also elevate their risk of vehicle collision (Keilsohn et al. 2018). Further research is needed to determine if increased pollinator habitat owing to restoration along roadsides outweighs the collision-related mortality.

Agricultural land use impacts pollinators in a number of ways. Land area in monoculture agriculture, where a single crop species or product is cultivated, by definition contain a minimum number of plant functional groups and thus supports a minimal diversity of pollinators. Thus, it represents the lowest quality habitat for pollinators and can generally sustain only those species that are able to meet their forage and nesting requirements with the homogeneous resources offered by the monoculture (Kennedy et al. 2013). Conventional tillage results in fields that contain no pollinator habitat, although pollinators may persist in areas surrounding fields and can offer services or repopulate as crops and associated plants grow and flower. Conventional agriculture also frequently involves the use of pesticides to eliminate harmful herbivores and weeds (discussed below).

A major component of North American agriculture is rangelands and ranching for livestock production. While rangelands are less carefully manicured and shaped than croplands or agroforestry systems, decades of livestock grazing can transform rangeland ecosystems, reducing overall cover and diversity of flowering forbs, degrading riparian areas, eliminating riparian plant species and compacting soils (Lázaro et al. 2016a, 2016b, Tadey 2015). Pollinators may encounter reduced forage and fewer nest sites as a result. Rangeland restoration efforts that benefit pollinators may include riparian area rebuilding, using fencing to prevent access to riparian areas while simultaneously using solar pumps to provide water, reducing livestock densities and resting ranges to allow soil recovery, and planting and protecting small patches of flowering forb and forage plants (Mitchell et al. 2013, Winsa et al. 2017).

Agroforestry also occurs in North America, including tree farms and other wood products enterprises, as well as crops such as coffee, which can be planted beneath shade trees and be a component of multistory agricultural systems. Mixed plantings including groundcover forbs, flowering shrubs, and trees can offer structurally diverse ecosystems for pollinator communities (Kay et al. 2020, Kuyah et al. 2017). Some pollinators nest in trees or dead wood and other stems, and structurally complex agroecosystems can also fulfill such nest requirements. As with field crops, agroforestry is least likely to support pollinators when trees and shrubs are planted in dense monocultures that are unlikely to support a diversity of flower functional groups (Jose 2012).

Invertebrate pollinator species are particularly susceptible to minor changes in habitat availability and connectedness due to their relatively small home ranges, especially for smaller-bodied solitary bees. There is a relatively positive association between body size and foraging radius, from a central point such as ground nests where females are provisioning resources for their eggs. What might be considered minor fluctuations in habitat connectedness or availability may have amplified ramifications for solitary bees; with some smaller species having home range radii as low as tens of meters (Greenleaf et al. 2007).

3.2 Introduced Species

Both non-native pollinators and non-native plants can have impacts on native pollinators although the consequences of non-native species introductions for native plant pollination is generally unknown and few are actually studied sufficiently to understand which plants or native pollinators may be affected by introduced species.

As previously discussed, the most widespread non-native pollinator in North America is the European honey bee (*A. mellifera*). There is growing evidence of environmental impacts from the honey bee, including effects from competition with native species, disease transmission, and parasite vectoring (Paini 2004, Thomson 2016). Honey bee colonies are moved, supplemented, and introduced into new ecosystems by human managers. Colonies can grow to contain a very large number of individuals and honey bees can be active in the environment for lengthened seasons, compared with solitary native bees, due to honey bee eusocial life histories. As a result, honey bees often dominate the pollinator community in abundance and activity. For example, they can compete for forage resources with native species, resulting in decreased native bee densities (Thomson 2016). Moreover, the sheer number of honey bees make them likely to encounter native insects, which results in high potential to transmit pathogens when hives are infected by diseases or parasites (Nanetti et al. 2021). Additionally, the presence of honey bee colonies, even in small densities, can have negative disrupting ramifications on plant-pollinator networks within local ecosystems and prolonged presence of commercial managed honey bee colonies may change the floral community composition within ecosystems over time (Valido et al. 2019).

Other managed pollinators previously mentioned, including *Bombus* spp., *Osmia lignaria*, and *Megachile rotundata*, are increasingly in use among agriculturalists and may also be moved around the landscape. Such introductions could restructure native pollinator communities by altering the competitive landscape and shifting forage distributions, as well as function, to increase disease spillover and spread as discussed below. Like *A. mellifera*, *B. terrestris* can compete with native pollinators and may be a disease vector in ecosystems where it has naturalized.

3.3 Pollution, Pesticides and Diseases

Pollution can affect soil, water and air, with consequences for pollinators. Sources can include chemical pesticides, herbicides and fertilizers, but also air pollutants. Air pollution has been correlated with pollinator declines via deposition and uptake from plants. As an example, increased nitrogen deposition from vehicle pollution in the San Francisco Bay Area of the United States was linked to increased growth of non-native grasses and thus decreased pollinator resources for an endangered butterfly (Weiss 1999). This finding drove an expanded examination of the US Endangered Species Act listings, which found 78 listed species are affected by nitrogen air pollution

(Hernández et al. 2016). Other impacts of air pollution include interference with floral scent trails followed by pollinators (McFrederick et al. 2008).

Many native bees nest in the soil, creating and provisioning brood cells for their young. Industrial activities can result in accumulation of heavy metals such as iron, copper, zinc, mercury and lead in soil. Experimental results show that pollinator reproduction can be hampered by toxic levels of metals in the soil (Moroń et al. 2014). Diversity and abundance of wild bees have been found to decrease along gradients of increasing heavy metals concentrations in soils and these effects can filter down to pollination services (Moroń et al. 2012). For example, visits by bees to sunflowers grown in lead-contaminated soils were significantly shorter than visits to control-group sunflowers (Sivakoff and Gardiner 2017).

Pesticides target invertebrates and are applied to plants and soils, directly impacting pollinators. Pesticide exposure results in diverse documented effects on insect pollinators, including reduced foraging efficiency, visitation rates, pollen delivery, and disruption of navigation abilities (Köhler and Triebskorn 2013, Stanley et al. 2015). Pollinator population declines have been observed in relation to increasing pesticide use (Walker and Wu 2017). Worldwide, use of neonicotinoids, which interfere with the central nervous systems of insects and impact their navigation, foraging ability, reproduction, and immune response, has spiked sharply in the past two decades (Martin-Culma and Arenas-Suárez 2018, van der Sluijs et al. 2013). These increases have been accompanied by significant decreases in bee populations, detected in disparate systems worldwide (Lambe 2018, Rundlöf et al. 2015, Woodcock et al. 2017). An analysis of county-level applications of pesticide in the eastern United States since 1997 showed a nine-fold increase in the lethality of pesticides based on active ingredients, far outstripping the actual increases in pesticide volumes during the same period (Douglas et al. 2020). Exposure to pesticides was identified as a major factor in the declines of *Bombus affinis* and *Hylaeus* spp. (Lambe 2018). Decreased butterfly populations have also been associated with increasing use of neonicotinoid pesticides in California, with small-bodied species exhibiting the highest vulnerability (Forister et al. 2016).

Many pollinators in North America—both, native and introduced—are subject to parasites and disease. *Bombus impatiens* and *B. occidentalis* colonies can become quite large and dense under managed conditions so they are subject to disease and parasite accumulation (Sachman-Ruiz et al. 2015). The alfalfa leafcutting bee (*Megachile rotundata*) is subject to chalkbrood, a larval fungal disease, as well as impacts of pesticide spillover (National Research Council 2007). Because honey bees have long been in use as managed agricultural species, honey bee diseases and parasites have been studied and tracked for much longer than native bee diseases, but diseases among wild bees are also of concern.

As noted earlier, honey bees and other managed bees can transmit diseases to wild bees (Graystock et al. 2016) and human-assisted movements of managed bees can introduce diseases to new regions and ecosystems. Deformed wing virus and other diseases can transfer from managed honey bee colonies to managed bumble bees. Parasites of particular concern include *Nosema bombi* and *Crithidia bombi*, as well as mites (Cameron et al. 2011, Meeus et al. 2011, Schweizer et al. 2012). Bees infected with gut parasites (*Nosema* spp.) exhibit increased vulnerability to the parasite *Varroa destructor*, with the combined effect of the two parasites elevating bee mortality (Bahreini and Currie 2015). A genetic analysis of shrinking bumble bee populations found higher rates of infection by the midgut microsporidian pathogen *Nosema bombi* and reduced genetic diversity overall compared with stable populations (Cameron et al. 2011). In the United States, the introduced horned mason bee (*Osmia cornifrons*) has been found to carry pathogenic fungi, with the potential to transmit pathogens to native congeners (Hedtke et al. 2015).

An emerging concern in bat conservation is white-nose syndrome, a fungal disease that attacks bats in their roosts. Since its emergence as a major threat to North American bats, the disease has been restricted to the more humid eastern Canada and United States (Hammerson et al. 2017). Detections in the West, however, raise concerns that the disease is spreading and may eventually appear among nectar-feeding bat colonies in the southwestern United States and Mexico (Maher et al. 2012).

3.4 Climate Change and Fire

Climate change exerts direct impacts on pollinators and also acts synergistically with other drivers of change. The scarcity of long-term data limits knowledge of the impact of climate change on pollinators (Dicks et al. 2021). However, altered temperature and precipitation can impose physiological stress on pollinators and their forage species, resulting in pollinator range shifts as they track a shifting climate envelope, or set of suitable climatic conditions (Thuiller 2004). Different taxonomic groups seem to shift their distributions at different rates. Climate change can also have indirect impacts through floral resource availability and phenology, as well as on the dynamics of pests, pathogens, predators and competitors (Le Conte and Navajas 2008, Potts et al. 2010).

Range shifts have been reported and projected for butterflies (Bedford et al. 2012), bees (Sirois-Delisle and Kerr 2018), and hummingbirds (Buermann et al. 2011), among other taxa. Climate change is expected to drive range shifts and expansions of species northward from the United States and to increase the establishment success of non-native species entering Canada from around the world (Kerr 2001, Sirois-Delisle and Kerr 2018, Walther et al. 2009). As pollinators shift their distributions, they may or may not co-occur with the same plant species or may become phenologically out of sync with the timing of flowering plants. Generalist pollinators may interact with other species in their new ranges, but specialist pollinators could become spatially separated from their previous partner plants. At the ecosystem scale, these changes may reconfigure interaction networks, with pollinators interacting with new plants (Dalsgaard et al. 2013). This reconfiguration is likely to create winners and losers, with some plants exhibiting improved reproductive success whereas others are negatively impacted.

Fire regime changes are driver of change as well. Native plant species, without fire adaptations, may fail to recover following fire events, leading to an invasion-fire cycle where burned areas are colonized by monocultures of non-native, flammable vegetation. As an example, the Sonoran Desert of northern Mexico and the southwestern United States is a major center of bee diversity on the continent with endemic species and unique adaptations, but is subject to expanding invasions of non-native grasses from Eurasia (McDonald and McPherson 2013). Native plants tolerate fire poorly but the continuous fuel created by plant invasions has introduced fire to this system. Fires kill native pollinator forage species such as cacti and legumes and lead to the further spread of grasses, reducing pollinator resources over ever-increasing land areas. Under this cycle, fire scars become zones of poor pollinator habitat, lacking native forage plants, and exhibiting reduced functional diversity and heightened fire frequency (Abatzoglou and Kolden 2011, Fuentes-Ramirez et al. 2016, Gray et al. 2014).

3.5 Other Factors

Other factors affecting pollinator populations interact to create additional impacts. Wind farms and solar farms are being added throughout North America. These renewable energy installations occupy large land areas and pose mortality threats to some pollinators. Bird and bat collisions with wind turbines are of particular concern (Drewitt and Langston 2006, Lintott et al. 2016, Marques et al. 2014). However, wind farm habitats may be beneficial for bees and other pollinators if the extensive areas of open groundcover at the base of turbines is high in flower abundance and diversity (Pustkowiak et al. 2018). Solar farms can also support groundcover with high pollinator habitat quality (Hernandez et al. 2019). On the other hand, birds and bats have been killed through collisions with solar panels, as well as by the excessive heat the panels produce (Upton 2014).

Population reductions occur when pollinators are killed or captured and removed from the wild. Bats, which are important pollinators in Mexico and the southwestern United States, may be killed intentionally by humans out of misplaced concerns about rabies and other zoonoses or because bats are considered nuisance animals (Arita and Santos-del-Prado 1999, O'Shea et al. 2016). Killing of hummingbirds to develop black market love charms may be responsible for thousands of hummingbird deaths each year (Ebersole 2018).

Multiple factors often appear to be linked to a species' decline. For example, the native, stingless bees managed throughout generations for honey production in Mexico now face impacts from climate change, deforestation, as well as competition and disease transmission from honey bees: an estimated 90 percent decrease in managed stingless bee hives has been documented over the past 40 years (Food and Agriculture Organization 2008). Environmental changes and losses of traditional management techniques have reduced *Melipona* stingless bee populations in some locations to critical levels (Villanueva-Gutiérrez et al. 2005).

The primary driver responsible for monarch butterfly losses appears to be habitat destruction, although pesticide use and climatic factors may also contribute (Thogmartin et al. 2017). Similar drivers of decline appear to be operational within the eastern and western monarch butterfly populations (Pelton et al. 2019, Thogmartin et al. 2017, US Fish and Wildlife Service 2020). A major challenge and opportunity in monarch butterfly research and conservation is its lengthy migratory pathway: the eastern population overwinters in Mexico and breeds in the United States and Canada. As a result, loss of habitat and nectar plants in any of the three countries can contribute to population declines—and indeed, measured declines likely stem from environmental change along the full migratory path of the butterfly (Inamine et al. 2016). On the other hand, any restoration efforts along its breeding and migration path can also benefit other pollinating species.

As noted earlier, *A. mellifera* colonies have suffered declines across the continent. Several causes have been proposed for this, with recent research exposing complex interactions among them. Simultaneous exposure to neonicotinoid pesticides and parasitic *Varroa destructor* mites, for example, reduces overwinter survival of honey bee individuals (Straub et al. 2019). Colony collapse disorder has occurred at heightened rates throughout various time periods in a classic disease outbreak pattern, although the disorder may instead rise and fall as a result of a combination of factors (Nearman and van Engelsdorp 2019). Losses in floral resource diversity as a result of agricultural intensification and reduced natural habitat access also diminishes the nutritional value of honey bees' forage plants and may make them more susceptible to parasites, diseases, and pesticides (Klein et al. 2017). Hives can be infected by protozoa, amoebas, and mites, which can both directly kill bees and lead to decreased foraging success and reduced hive fitness (Bradbear 1988). Honey bee production in Mexico is affected by the spread of diseases and parasites such as the *Varroa* mite, as well as by climate change driving unpredictable weather events and changes in key forage plant distribution, and toxicity from pesticides. Sources of mortality in honey bees in Ontario, Canada, include outbreaks of the *Varroa destructor* mite, *Nosema* spp. fungal digestive pathogens, and the bacteria *Paenibacillus larvae*, all in combination with weather fluctuations and pesticide exposures (Ontario Ministry of Agriculture, Food, and Rural Affairs, 2018).

3.6 Summary and Knowledge Gaps

Drivers of change impact pollinators of all taxa in all habitat types. Pollinators face habitat loss, reduced forage, direct effects of pesticides, pollution, disease and altered competition regimes. Individual studies have documented pollinator declines in a wide range of systems. However, many knowledge gaps remain. Due to limited resources and jurisdictional complexity, pollinators receive limited attention and studies have occurred in only a fraction of habitats and for only a fraction of pollinator taxa in North America. Insects are particularly difficult to identify and study, so there is a lack of baseline information for many species and, thus, limited ability to quantitatively detect population declines (National Research Council 2007).

Drivers of change can operate synergistically with one another (Brook et al. 2008), perhaps leading to nonlinear or multiplicative effects; as a result, changes to many pollinator populations remain uncertain and difficult to predict. In summary, shared conservation challenges across the three countries include habitat loss and degradation spurred by expanding agriculture and urbanization; introduced pollinator competitors, predators, diseases, and parasites; pesticide contamination; energy development and transportation corridors; and climate change (National Research Council 2007).

3.7 Key Messages

- There are a number of drivers of change for known pollinator population declines in North America, although many unanswered questions and avenues for further research and monitoring remain. Drivers of change include habitat loss and fragmentation; land-use change; certain agricultural practices; invasive species; pollution; pesticides; pests and diseases; climate change; fire; and other factors as well as compound interactions of drivers.
- The most widespread and impactful driver of change for North American pollinators is habitat loss stemming from land-use change. In the United States, non-honey bees, butterflies, bats and other managed or wild pollinators are impacted by habitat loss and degradation, and there is strong evidence that, for some species, habitat loss has led to population declines. For North American invertebrates included on the IUCN Red List, the most common listed cause is general habitat loss, followed by deforestation and climate change.
- Pollution, pesticides and pests can all impact native pollinators both directly and indirectly through flower availability. Invasive species can impact native species through competition for resources and the spread of diseases and pests.
- Climate change also appears to be an important driver. It exerts direct impacts on pollinators and can also act synergistically with other drivers of change. Changes in temperature and precipitation can impose physiological stress on pollinators and their forage species.
- However, there remain many unknowns. Due to limited resources and jurisdictional complexities, studies have been conducted on only a fraction of habitats and for only a fraction of pollinator taxa in North America. Insects are particularly difficult to identify and study, so there is a lack of baseline information for many species and thus limited ability to

quantitatively detect population declines. Such changes continue to occur, perhaps in synergy with one another, leading to nonlinear or multiplicative effects and making consequences difficult to predict.

- Shared conservation challenges across the three countries include addressing: habitat loss and degradation spurred by expanding agriculture, urbanization and transportation and energy corridors; introduced pollinator competitors, predators, diseases, and parasites; pollution and pesticide contamination; and climate change. Herein lies an opportunity for the three countries to work together on these shared conservation challenges.

4 Pollinators: Ecosystem Services and Human Dimensions

Pollinators are essential to functioning ecosystems, and to the services offered by those ecosystems to local communities. Various sectors and communities across North America benefit from pollination. Developing conservation frameworks and approaches to address complex social-ecological systems requires a broad perspective that acknowledges the various aspects of ecological systems and the intersecting dimensions of human use and interaction with those systems. Social sciences are increasingly integrated in conservation practices traditionally led by natural sciences, helping to address social and institutional barriers to conservation. Conservation social sciences link classic social science theories, methods and analyses to applied work in order to understand the relevance of social phenomena to conservation via social processes and individual attributes (Bennett et al 2017).

Aware of the many ecosystem services and socio-ecological benefits provided by pollinators to local communities in the North American region, the governments of Canada, Mexico and the United States, through the CEC project "Strengthening Regional Pollinator Conservation to Secure Local Benefits," also aimed to promote stakeholder engagement and increase awareness of these benefits. In this context, the CEC convened a workshop in December 2020 to explore the human dimensions of pollinator conservation and the many ways local communities interact with pollinators and the ecosystems in which they are found.

This section reviews the importance of pollinators in terms of ecosystem services and benefits to communities, before summarizing the main points from the introductory workshop on how social sciences and human dimension approaches can help pollinator conservation.

4.1 Ecosystem Services

Ecosystem services are defined as those services that are provided by ecosystems and are of direct and measurable benefit to humans (Daily 1997, Mace et al. 2012). The Millennium Ecosystem Assessment (MEA) adopted a framework of four ecosystem service categories, each encompassing a set of distinct services (MEA 2005). The categories were provisioning services, regulating services, cultural services, and supporting services.

Pollination as a process is generally included in the regulating services category since it is essential for the maintenance of diverse and abundant plants that contribute many other processes and services. As noted earlier, more than 85 percent of plant species worldwide are animal-pollinated, either depending on or benefiting from pollinator activities (Ollerton 2017). Pollinators span a wide diversity of functional groups based on their body shapes, sizes, and behaviors, forming complex interaction networks that help to maximize the diversity of traits displayed by plants and animals in an ecosystem. Diverse, connected ecological communities, in turn, offer a host of environmental benefits to local communities. Pollinators permit gene flow between plants, linking populations and enabling or boosting reproduction. Pollinators contribute direct ecosystem services by pollinating crops, traditionally harvested plants and non-crop plants that supply important resources to humans (Vanbergen and the Insects Pollinator Initiative 2013). One-third of commercially-grown crops globally are pollinated by animals (Food and Agriculture Organization 2009).

Valuation of pollination as an ecosystem service is complex but may include calculating the market values of crops reliant on pollination, the cost of renting managed pollinators for commercial pollination, or pollination replacement costs if wild and/or managed pollinators disappear from a system (Allsopp et al. 2008). The IPBES (2016) has estimated that pollinators provide between US$235–$577 billion in agricultural ecosystem services globally, with impacts extending far beyond the agricultural sector. Agricultural communities are particularly dependent on pollinator activities and functions.

A diversity of pollinator functional groups is critical for sustaining ecosystem services, supporting diverse human endeavors, and bolstering economic activity across the three countries. While the largest areas of land used to grow crop in North America are devoted to wind-pollinated species such as corn, wheat, sorghum, and other grains, pollinator-dependent agriculture can be found in communities across the continent and include large corporate or industrial farms, subsistence farms, organic and boutique agriculture, hobby gardening and everything in between. Important animal-pollinated crops include orchard trees, coffee, flower-producing row crops like alfalfa, soy, tomato, potato, tobacco, and cotton, and more labor-intensive or specialty crops such as vineyards, sunflowers, fruits and berries.

Agriculture and the agri-food manufacturing sector accounted for C$49 billion of Canada's gross domestic product in 2015 and is a particularly important contributor to the economies of Ontario, Quebec, Alberta and Saskatchewan (Statistics Canada 2019). Large-scale agriculture includes cattle farms, wheat and other grains, as well as oilseed crops, which are not directly dependent upon pollinators (Everitt et al. 1996). However, pollinators are essential for the crops occupying about 13 percent of the cultivated land area in Canada, some of which feeds livestock, which in turn contributes about half of Canada's food supply (Richards and Kevan 2002). Agriculture in Canada includes a wide diversity of pollinator-dependent crops grown across the country, concentrated in the southern latitudes of the country, where sunlight is most abundant and temperatures are highest. Canola is the most valuable crop in Canada; it was the largest contributor to Canadian GDP, reaching $4.6 billion in 2015 (Statistics Canada 2019) and is pollinator-dependent (Alberta Biodiversity Monitoring Institute 2018). Canada ranks first in the world in canola production and second in blueberry production—also dependent on pollination (Agriculture and Agri-Food Canada 2014).

Bee-pollinated agriculture is thus economically important in Canada (Richards and Kevan 2002), with pollination by honey bees valued at $2 billion (Agriculture and Agri-Food Canada 2014). Beekeeping is itself an important agricultural industry in Canada, for the production of honey and other hive products and delivering valuable pollination services to farmers of orchard fruits, many berries, vegetables, forage and the production of hybrid canola seed. The total economic contribution of honey bee pollination through direct additional harvest value was about C$2.57 billion annually in 2017 and $4 to $5.5 billion per year when the contribution of honey bee pollination to the production of hybrid canola seed is included (Agriculture and Agri-Food Canada 2019). Additional pollination is provided by more than 500 native bee species in Canada, as well as non-bee pollinators (Richards and Kevan 2002). Boutique or hobby production of pollinator-dependent crops is also important, whether in the form of small-scale business endeavors or gardens and other not-for-profit efforts.

The US Department of Agriculture (2020) reports that more than 100 crops grown in the United States rely on pollinators and that the added revenue to crop production from pollinators is valued at $18 billion. The total annual value of honey bee products and services sold is approximately US$700 million (US Department of Agriculture 2020). In the United States, animal-pollinated agricultural plants were valued at $71.9 billion in 2009 figures (Calderone 2012). Out of that total, $17.1 billion was attributable to the managed honey bee, with the remainder attributable to other insect pollinators, including both managed and wild species (Calderone 2012). The value is higher when it includes the full contribution of pollinators to ecosystem services and functions including rangeland health and productivity, soil and water retention, and carbon sequestration. Market values include both directly pollinator-dependent crops such as fruits and nuts and indirectly pollinator-dependent crops that do not produce a pollinator-dependent product but are grown from seed produced via animal-mediated pollination (e.g., vegetables).

The Midwest, Northwest, and Southeast all cultivate pollinator-dependent canola. Rangelands constitute 31 percent of the land area of the United States (Havstad et al. 2009) and the cattle industry contributed $391 billion to the US economy in 2021 (US Department of Agriculture 2021b). A critical component of rangeland diversity is the pollinator community. Although forage grasses are wind-pollinated, pollinators sustain rangeland biodiversity by promoting reproduction of forbs that retain soil, sustain wildlife, and often themselves serve as supplemental forage species (Gilgert and Vaughan 2011).

Like the rest of the continent, Mexico supports large agricultural industries, but also exhibits a particularly high diversity of crops dependent upon animal pollinators: 236 out of 316 crops cultivated in Mexico are for human consumption, and animals pollinate 85 percent of crops that are cultivated for edible fruits or seeds (Ashworth et al. 2009). Avocados, tomatoes and coffee are animal-pollinated and are among the country's top ten agricultural exports (Rhoda and Burton 2010). Animal-pollinated crops produce much higher yield by volume and contribute twice as much revenue per acre as non-animal-pollinated crops (Ashworth et al. 2009), emphasizing the importance of these agricultural varieties for the income and subsistence of Mexican farmers. A growing interest in the pollinators of these crops has led to increasing research, but many knowledge gaps persist (e.g., Castañeda-Vildózola et al. 1999, Villegas et al. 2000).

Human uses of pollinator-dependent plants go well beyond market-traded crops. For example, Mexico is home to 58 Indigenous groups speaking 291 languages, and more than 7,000 native plants with human uses have been identified in ethnobotanical studies (Casas and Parra 2007). There is a high proportion of subsistence farming and small agricultural communities in Mexico, where half the rural population works in agriculture and about three-quarters of the farms are small (United Nations Conference on Trade and Development 2014). Although agricultural incomes for small farmers have declined in recent decades (United Nations Conference on Trade and Development 2014), agriculture remains an important part of the economic fabric of rural Mexico, while also contributing to food security.

Although managed pollinators like honey bees are introduced to and maintained in many agricultural communities, wild pollinators also interact with crops (including both native and non-native plant species) and can carry out as much or more pollen transfer than the honey bee. As noted, wild pollinators can include diverse taxa, such as bees, butterflies and moths, flies, hummingbirds and bats, and can therefore interact with a diverse set of agricultural crops. For example, wild bees pollinate some key crops, such as chilis (Landaverde-González et al. 2017), the biofuel crop *Jatropha curcas* (Romero and Quezada-Euán 2013), and various squash crops (Pinkus-Rendon et al. 2005). Wild pollinator activity is critical for reproduction of many crops and native plant species and managing for wild bee, fly and moth pollination holds promise for agriculture. For example, increased seed yields in canola fields in Canada were measured when wild bee populations increased (Morandin and Winston 2005) and wild bee pollination increased fruit yields in strawberries relative to *A. mellifera* pollination (MacInnis and Forrest 2019). These and similar findings have motivated research into mechanisms for boosting wild bee populations and diversity in agricultural systems across Canada (Brook et al. 2008b, Moisan-DeSerres et al. 2015, McKechnie et al. 2017, Sheffield et al. 2008).

Pollinators appear in Indigenous stories, artwork, and traditions across all three countries. Indigenous communities traditionally recognize the importance of pollinator interactions for native plants providing food, medicine, fibers, and dyes. Additionally, pollinator migration, emergence, and activity are important seasonal events that help indicate cyclical annual change. Indigenous agricultural practices rely on diverse and abundant native pollinators, highlighting the importance of pollinators to cultural diversity across North America. The Maya of Mexico practiced farming in which trees and diverse groundcover food crops were intermixed, so that a given agricultural area contributed food products, medicines, and ceremonial products (Nakao 2017); modern Indigenous communities practice similar agriculture. In addition, home gardens are a common source of supplemental food in Mexico for Indigenous and non-Indigenous families alike (Nakao 2017). As noted earlier, for nearly 2000 years, beginning with the ancient Maya, native stingless *Melipona* bees have been managed to support agriculture in Indigenous communities (Nakao 2017). Pollinator conservation and management efforts across the region can benefit from traditional ecological knowledge, and conservation of pollinators is essential to the conservation of cultural heritage (Kennedy and Arghiris 2019, Wyllie de Echeverria and Thornton 2019).

A new trend in North America is the development of community pollinator gardens, retention of wildflower spaces, and landscaping of public areas with native, flowering plants. This contrasts with previous practice in which developed areas were primarily centered around manicured lawns and introduced landscaping plants. This shift is indicative of a heightened sense of value placed on pollinators across the continent by communities.

Understanding how local communities interact with pollinators is important for the development of pollinator conservation measures. Local communities can influence the availability of pollinator resources across the landscape, connectivity of pollinator habitats along migration routes, the prevalence of threats such as pesticides, competition with non-native managed pollinators, and direct exploitation of pollinator species, as well as the likelihood of mitigation efforts such as habitat restoration activities, shifts to non-conventional agricultural techniques, and removals of non-native species. They can also apply social pressure and hold stakeholders accountable when best management practices are not being followed.

4.2 Social Sciences and Human Dimensions in Conservation—North American Perspectives

Conceptual and theoretical foundations of social sciences and human dimensions can be used to advance pollinator conservation by shedding light on the causes and complexities of conservation challenges, facilitating engagement with stakeholders, expanding our understanding of conservation behaviors, and improving management and governmental processes (Hall and Martins 2020). Since conservation is about solving problems, the classic process to achieving conservation is to develop a specific strategy and link that strategy to conservation targets; human dimensions expertise can help to make those linkages between social drivers and biological outcomes.

"Human dimensions" can be thought of as a combination of people, processes, and institutions, their influence on how society measures success and failure, and how it adapts accordingly. Different institutions may view different outcomes as successful. Key principles for including human dimensions in conservation work include the involvement of social scientists, building relationships with local people, learning about different cultures, seeking out less obvious drivers and influences, learning continuously and adapting to change.

Relevant experts from North America convened in December 2020 for a virtual meeting on applying human dimensions to pollinator conservation, and the following insights emerged from that meeting and are based on experts' opinions.

Collaboration is complex within one country, let alone when scaling across several countries. Variation within and between countries must be taken into account. However, broad, abstract concepts can be identified that will have relevance at the local scale when put into practice, connecting big ideas to local implementation, regardless of the country in question. Social science may not give a single answer, but it helps with thinking through the options and connecting the human dimensions to biological outcomes that will enable us to better understand problems and identify pathways for solutions.

An understanding of the "people" element includes their perceptions, attitudes, and behaviors. The role of individuals must be considered since a particular challenge will manifest differently within different social groups. It is important to reach out to those who might be least influential, in addition to the most influential, with regard to a particular challenge; for example, in some regions, rural individuals may have less influence over policy or resources than urban individuals but may carry knowledge of pollinator dynamics or diversity that could inform effective conservation planning. Another important angle is land-based practices and knowledge (the things that people do, and the knowledge that builds up through the years or generations of applying that experience). For example, local people can have local environmental knowledge about how practices affect the environment that can inform pollinator conservation.

Processes include active strategies and engagement intended to promote social capital formation that creates equitable space for all voices, strategic planning, anticipatory or responsive activities, collaboration and learning. Institutions—the structures and rules that govern social, political and economic relations—are important to shaping behaviors (and understanding those behaviors) and understanding and addressing power dynamics. Institutions can include both formal and informal rules. Formal rules include laws and property rights. One such rule is land tenure, which dictates which resources can be used, for how long, under what conditions, as well as how rights are transferred. Informal rules include customs and cultural norms or expectations and can be particularly important in rural or Indigenous communities. Formal rules influence who can be excluded from resources and who is involved in the rule-making itself. The terms "rights holders," the people and organizations who hold the rights to make decisions relevant to a conservation target, or "responsibility holders," are terms preferable to "stakeholders," as they more accurately represent the people involved in the focal issue.

Scales and hierarchies are also important. Networks and relationships must be long-term in order to be effective and such efforts must last longer than any given project. Long-lasting relationships and networks can be challenging to create and maintain because of the massive geography and spatially diffuse nature of pollinator conservation across North America. Furthermore, it can be difficult to translate local relationships to continental-scale effectiveness. However, there are already many groups working on pollinator conservation that may be leveraged rather than superseded (see some examples in Appendix 2) and coalitions of existing efforts may offer a promising path. For such coalition-building to succeed, a clear, specific, shared vision is essential; as participatory efforts fail when expectations are not met. It is important to have a shared vision-space, which is a set of constraints and limits within which visioning, brainstorming, and the generation of well-defined and foundational ideas can occur. It is likely that a combination of novel and powerful coalitions as well as advances on the social or biological side are most important ingredients for success.

There are some important tools and approaches for integrating human dimensions in conservation work. It will be critical both to identify audience and scope to access a common purpose and to find a framing that is broadly compelling, such as food systems and food security. Thus, future work should focus on identifying “throughlines” (common or consistent elements or themes that run through the components' messaging, events and strategies of a conservation campaign or effort) that can be introduced across the continent to advance pollinator conservation in a cohesive and effective way. It is also important to identify barriers to changing public perception and to acknowledge and address the multiple perspectives and needs of different stakeholders in particular messages in order to ensure people feel included. As an example, for monarch conservation, the social outcomes desired from projects were identified, as well as evaluation techniques. This approach both broadened the conversation toward a more holistic understanding of the problem and helped to focus biological questions.

Stakeholders, or rights holders, are the people and organizations that have a stake in the outcome of an effort and are involved in pollinator conservation in each country. Understanding which actors are on board and which are not may enable a different view of the issue. “Power over” (the ability to persuade others to do something) versus “power to” (the capacity to do something) and “power with” (the ability of a group to do something collectively) are important considerations with regard to those who do and do not enter dialogue and share perspectives. Each country has a number of stakeholders. It will be difficult to map actors at the trinational level, but for every recommended intervention, identifying a new suite of actors and impacted entities will be necessary. It may be helpful to break such a process into stages and into the depth to which connection and intervention is necessary (i.e., for some stakeholders it may be necessary to just share information while for others it may be necessary to solicit active participation). Again, identifying “throughlines” and messaging that resonate across the board will be very important for successful outcomes.

In Canada, stakeholders include but are not limited to: governmental entities such as Agriculture and Agri-Food Canada, Environment and Climate Change Canada, and Health Canada, as well as other federal and provincial agencies responsible for managing wildlife and at-risk species; public stakeholders such as the agricultural sector, Indigenous peoples including Indigenous agriculturalists, commercial honey producers, industrial entities such as pesticide producers, and the general public. Other Canadian stakeholders include academics interested in pollinator conservation, municipal- and provincial-level transportation and energy corridor managers and crown corporations, as well as private transportation and energy corridor managers, and multiple nongovernment organizations, for example, Pollinator Partnership Canada, the Montreal Insectarium and the Canadian Wildlife Federation.

In Mexico, stakeholders include but are not limited to: many small producers in Indigenous communities, individuals raising native bees and local governments pushing for pollinator protection; at the federal level, the Ministry of Agriculture (*Secretaría de Agricultura y Desarrollo*

Rural) is the lead agency for the National Pollinator Strategy along with the Ministry of Environment (Semarnat), while other agencies include the National Service for Agri-Food Health, Safety and Quality (Senasica), the National Institute of Forestry, Crop and Livestock Research (Inifap) and the National Council of Science and Technology (Conacyt). Additional stakeholders include agricultural and forestry industries, honey producers, pesticide and genetically modified organisms industries as well as other industries interested in pollinator protection as a form of environmental philanthropy. Academics and conservation and sustainable development NGOs are also important stakeholders in Mexico.

In the United States, stakeholders include but are not limited to: federal agencies such as the US Fish and Wildlife Service, the US Geological Survey, and the Department of Agriculture; state resource management agencies; several NGOs including Pollinator Partnership and the Xerces Society, many academic institutions, the Monarch Joint Venture, and the North American Pollinator Protection Campaign.

It may be useful to consider transdisciplinary principles to bridge knowledge gaps and facilitate interdisciplinary and intersectoral dialogue. "Transdisciplinary" occurs when actors/players come together to solve an issue. It is issue-centric and actors do not identify themselves with labels, such as social scientist or ecologist or agricultural industry. Instead, people set aside those labels and affiliations and come together to bring expertise, experiences and different knowledge systems to solve a problem. It is important to acknowledge how and why one feels and thinks in order to understand where people are coming from. This allows understanding of the roots of conflict in order to get beyond them.

The "common good" framework that has been explored in social science literature may provide an appropriate focal example for pollinator conservation through an emphasis on food security, for instance. One main advantage of the "common good" framework is that it choreographs actors to benefit the community rather than individual interests and it may provide a vision that could include all stakeholders (). There is a rich body of literature surrounding the common good, and that literature is focused on applied contexts. This is a potentially powerful vision that can help people with diverse needs and perspectives coalesce around, since the services provided by pollinators is something people can understand and accept, and it ties to their right for food security. Food security is easily understood as a basic human right (see Article 25, Universal Declaration of Human Rights) and could assist a reframing of the problem from a public policy perspective, which in turn will guide the eventual development of policy and the shaping of solutions. Social sciences can take such issues out of the private sphere and into the public space, providing an essential shift for guiding public policy that can serve the common good.

4.3 Summary and Knowledge Gaps

Pollinators benefit local communities by contributing to all ecosystem services through their activities in plant communities underlying ecosystem function. Pollinators specifically support agriculture, recreation, ecotourism, and culturally important plants and plant communities, making them fundamental to local community economies and cultural identities. As pollinator communities fluctuate and species' assemblages change, it remains unknown how ecosystem services will be affected. If pollinator services are redundant across species, changes in relative densities of pollinator species may have little impact on plant communities and their functions. However, in cases where pollinator services are not redundant, the loss or decline of certain species may fundamentally alter pollination effectiveness and the plant community itself.

The CEC aims to identify common conservation needs and challenges that can be addressed and scaled up to the continental level. Bringing more social science perspectives into pollinator conservation can help find solutions to complex problems, although the paucity of social scientists on staff within conservation agencies means that knowledge and capacity barriers will remain.

4.4 Key Messages

- Pollinators are essential to functioning ecosystems, and to the services offered by those ecosystems to local communities. Developing conservation frameworks and approaches to address complex social-ecological systems requires a broad perspective that acknowledges the various aspects of ecological systems and the intersecting dimensions of human use and interaction with those systems.
- Pollination is an important ecosystem service and pollinators contribute significantly to agriculture in all three countries and to food security in general.
- Recognizing that conservation requires more than just natural sciences, social sciences can help advance conservation success by shedding light on the causes and complexities of conservation challenges, facilitating engagement with stakeholders, expanding understanding of conservation behaviors, and improving management and governmental processes.
- Human dimensions combines people, processes, and institutions, their influence on how society measures success and failure and how it adapts accordingly; different institutions view different outcomes as successful. Key principles for including human dimensions in conservation work include the involvement of social scientists, building relationships with local people, learning about different cultures, seeking out less obvious drivers and influences, learning continuously and adapting to change. Since conservation is about solving problems, the classic process to achieving conservation is to develop a specific strategy and link that strategy to conservation targets; human dimensions expertise can help to make those linkages between social drivers and biological outcomes.
- Collaboration is complex within one country, let alone scaling across the continent. It will be critical both to identify audience and scope to access a common purpose and to find a framing that is broadly compelling, such as food systems and food security. Future work should focus on identifying throughlines, or common themes that run through the components, messaging, events and strategies of a conservation campaign or effort, that can be introduced across the continent to advance pollinator conservation in a cohesive and effective way. It is important to address the needs and perspectives of different stakeholders in a particular message in order to identify barriers to changing public perception and to acknowledge multiple perspectives and address them in order to ensure people feel included.

5 Conclusion and Recommendations

Concern over pollinators is global, and similar reports and efforts have occurred in a wide diversity of international and national contexts. In light of the IPBES report's findings, researchers have made a variety of policy recommendations including: enhanced regulation of pesticides and genetically-modified crops; a reduced reliance on managed pollinators that can act as competitors and sources of disease for wild populations; increased integration of ecological principles into agricultural planting to elevate farm habitat quality for pollinators; increased integration of social sciences and the humanities in operationalizing pollinator conservation; distribution of pollinator refugia across the landscape to broaden and stabilize provision of ecosystem services; increased pollinator habitat in urban areas; and increase pollinator monitoring and research (Dicks et al. 2016, Jia et al. 2018, Vadrot et al. 2018).

Pollinators offer a flagship opportunity for conservation in North America, where meaningful efforts can be undertaken at nearly any scale, in nearly any region. From innovative continental collaborations to public-private partnerships and small-scale backyard actions, opportunities to address and reverse causes of pollinator decline are diverse and multi-faceted. Strategies linking these scales and sectors can help imperiled pollinator species while simultaneously connecting more people to nature, ensuring core ecosystem functions and mitigating future risks to food systems. Pollinator conservation planning should be broad in spatial and temporal scale and must encompass diverse habitats, ecosystems and pollinator taxa. Coordination of planning and efforts between countries, among and between jurisdictions/agencies/stakeholders will be critical. Uniting stakeholders around this shared mission must build on existing cooperation to ensure a sustainable future for all species of pollinators and the plants, people and planet that depend on them. Messaging and information sharing are also necessary to support collaboration and prevent confusion.

Pollinator conservation in North America will require trinational action, involving a wide range of institutions, organizations, and individuals. This section includes identified priorities for North American collaboration, based on the biological sciences and practices required to expand knowledge of pollinator diversity, trends and drivers of change. It also provides recommendations for increasing the integration of human dimensions/social sciences and practices in pollinator conservation. These priority areas and recommendations require funding, information flow, and direction. Their implementation will require the involvement and collaboration of many actors and sectors of society across the three countries.

5.1 Priorities for North American Collaboration

The collaborative work undertaken over the course of the CEC project, including the expert meeting held in Oaxaca City, Mexico in February 2020, the virtual expert meeting in December 2020, and the previous sections of this report highlighted a number of knowledge gaps that would benefit from prioritization as well as many areas that could benefit substantially from focused, collaborative efforts across North America. Possible actions to advance regional collaboration for pollinator conservation are:

- **Prioritize research and monitoring**

Long-term monitoring data are essential for designing pollinator conservation programs that respond to population changes by taxa, region and driver of change. Pollinator conservation in North America should prioritize collaborative research and monitoring. It is important that countries design continental monitoring programs with **standardized methodologies, centralized data repositories, and metrics of effort** so population indices can be derived from monitoring data. This will require funding for research and direction for agencies to coordinate with their counterparts in other countries for trinational coordination and oversight. Research topics are wide ranging and include: **pollinator responses to non-native plant species across various taxa and ecosystems; pollinator habitat range shifts in response to climate change; physiological and phenological**

studies of pollinator and plant responses to climate change and the probable effects on pollinators and on plant-pollinator interactions; disease, pests and transmission routes between native and introduced species; exploring new efficient sampling methods, such as metabarcoding and eDNA to fill gaps in natural history knowledge; collaborating with local and Indigenous communities; and encouraging the use of citizen/community science data for pollinator and plant monitoring across the three countries.

- **Build scientific capacity to scale-up monitoring efforts over large areas**

Identifying native pollinators, particularly insects, often requires advanced expertise. The number of existing institutions that are able to process samples or otherwise identify and document the occurrence will likely continue to be a limiting factor. Attempts to mobilize widespread data collection in support of monitoring population status and trends over large areas will likely encounter a bottleneck of existing capacity to process the data. Novel approaches may be necessary to align government, NGO, museum, and academic partners to create a pipeline of technical expertise and a network of collaborators capable of identifying pollinators in a timely and economically efficient manner.

- **Prioritize pollinator habitat protection and restoration**

Whether habitats are converted to agriculture or other development, altered by climate change or degraded by invasive species, pollinator populations decline in response to habitat losses. There is a need for collaboration to **address pollinator habitat protection and restoration**, including: **setting area targets and standards; identifying and prioritizing areas for protection and restoration; prioritizing use of native plants; establishing/promoting best management practices for pollinator conservation by various sectors and industries; and implementing agricultural practices such as conservation tillage, cover-cropping, living fences, hedgerows and other mechanisms to protect and create pollinator habitat**.

- **Improve research on agricultural practices and pesticide impacts**

There is a need for better qualitative and quantitative information about the **impacts of different agricultural practices** and the **use of existing and emerging pesticides**, as well as pesticide alternatives and pesticide mitigation methods that meet the needs of agriculturalists while reducing harm to pollinators. Best management practices for **pollinator-friendly agriculture** as well as pesticide, use should be developed. Importantly, tracking and record-keeping of pesticide use, including volume, concentration, and application rates, should be implemented formally.

- **Study impacts of managed pollinators**

Pollinator conservation efforts should assess the impact of managed honey bees and other non-native species on native pollinators. Holistic pollinator conservation strategies in North America should include measures that **improve practices for managed bee resources in agricultural and rural landscapes, bolster native bee populations and communities across habitat types and regions and protect critical native bee refugia and centers of richness and endemism in the face of environmental change**. There should be more effort to track managed movement and use of honey bees and other managed pollinators to facilitate risk management and to develop country-specific best management practices for managed pollinators of different species.

- **Expand education and alternative practices**

North American pollinator conservation should prioritize **communication of the importance of the role of pollinators in ecosystem services broadly, and for food security more specifically, and**

develop and implement community-based pollinator education and habitat programs. Trilateral collaboration should also focus on promoting and expanding citizen/community science programs and outreach to local community groups, including underrepresented groups and promoting the development of local and regional guides for the identification of pollinators and the plants they pollinate.

- **Identify and develop incentives and resources**

Policy tools that promote pollinator conservation should be explored and possibly implemented, such as: **incentivizing pollinator conservation actions across public and private sectors; funding pollinator outreach activities by universities, botanical gardens, conservation organizations, knowledge transfer entities and other information sources; removing tax disincentives and barriers to pollinator conservation activities;** and **developing Payments for Ecosystem Services programs (mitigation or ecosystem market trading system programs) focused on pollinator support efforts**.

- **Support strategic decision-making**

Strategic decision making will benefit from improved understanding of where conservation efforts are most needed and where information gaps are most significant. Geospatial depictions of pollinator occurrence can serve to illuminate broad-scale geographic patterns and changes over time. Further, such tools can serve to drive coordinated monitoring efforts and promote coordinate data management practices and data sharing across national boundaries.

5.2 Recommendations on Applying Human Dimensions to Pollinator Conservation

The deliberate integration of social sciences into pollinator conservation allows decision-making to be linked directly to social drivers of change, social structures able to implement solutions and social behaviors that will facilitate or impede effective progress. In this way, pollinator conservation can showcase the importance of the human dimensions of conservation as a lens through which to seek less obvious drivers and influences and adapt to change.

The following highlights recommendations emanating from exchanges on the human dimensions of pollinator conservation between experts from the three countries as part of the CEC project, in particular the virtual expert meeting held in December 2020. Overall, participants recommended to:

- **Integrate social science into pollinator conservation**

The first and primary recommendation on the human dimension side is to integrate social science early in the process of pollinator conservation planning. **The social sciences can be critical to success in conservation efforts for their ability to illuminate the causes, complexities and social consequences of conservation challenges, provide guidance for engagement with stakeholders, enabling an understanding of stakeholder behaviors,** and **facilitate the development of effective solutions**. Social phenomena, social processes and individual attributes are all integrated in conservation challenges. Conservation problem solving therefore requires a theoretical understanding of these social elements, which can then be applied in real-world systems.

- **Apply a "common good" framework**

The second recommendation is to explore further application of a "common good" framework as it may contribute to shared pollinator conservation goals and understanding among stakeholders spanning different cultures. A common good framework is a perspective that highlights what is shared and good for all members of a community. This type of framework can provide a unifying concept linking stakeholders to the collective benefits derived from pollinators and pollination services, recognizing the centrality of pollinators to food security. **The common good framework of social science may be a useful unifying "throughline" that can engage stakeholders across pollinator conservation due to the importance of pollinators to food security**. As a public good, pollination is both free from ownership and essential to human systems, communities and prosperity. As a result, it eludes traditional assignment of management responsibility but is also an area of high importance, relevant to human rights and central to broad goals of conservation and sustainability.

- **Conduct stakeholder mapping**

A third recommendation is to **perform a robust exercise in stakeholder mapping, in order to facilitate networking, knowledge sharing and the development of workable pollinator conservation solutions**. Identifying stakeholders across social, economic, political and institutional systems is a particular challenge in trinational pollinator conservation because pollinators are essential to food security and ecosystem services that affect all communities and ecosystems across the continent. A formalized effort to map stakeholders will be required in order to expand the conversation across those communities and ecosystems and work toward solutions that are tenable and effective. Given the complexities of trying to map stakeholders in any single country and that stakeholders will differ across countries, it is recommended that these mapping exercises first happen at the national scales or at regional scales where pollinator conservation is a priority.

- **Evaluate effectiveness**

A fourth recommendation is that pollinator conservation efforts include **a formal evaluation of the effectiveness of the strategies that are eventually to be employed**. Assessment of outcomes is important to allow appropriate adaptation and to ensure that solutions are linked to challenges. Pollinator conservation can serve as a "proof of concept" to demonstrate the broad value of integrated socio-ecological approaches for applied conservation problem-solving, but requires some assessment of effectiveness.

5.3 Key Messages

- Pollinators offer a flagship opportunity for conservation in North America, where meaningful efforts can be undertaken at nearly any scale, in nearly any region. There is a need for pollinator conservation planning that is broad in spatial and temporal scale and encompasses diverse habitats, ecosystems, and pollinator taxa. Coordination of planning and efforts with each country, among and between jurisdictions/agencies/stakeholders will be critical. From innovative continental collaborations to public-private partnerships and small-scale backyard actions, opportunities to address and reverse causes of pollinator decline are diverse and multi-faceted, representing a tremendous opportunity.
- Pollinator conservation in North America will require trinational action involving a wide range of institutions, organizations and individuals. This document identified priorities for North American collaboration based on the biological sciences and practices required to expand knowledge of pollinator diversity, trends and drivers of change. It also provided recommendations for increasing the integration of human dimensions/social sciences and practices in pollinator conservation. These priority areas and recommendations will require

funding, information flow, and direction. Their implementation will require the involvement and collaboration of many actors and sectors of society across the three countries.

- Recommendations for future collaborative efforts at the North American level are to: 1) prioritize monitoring of pollinators; 2) prioritize pollinator habitat conservation; 3) research agricultural practices and pesticide impacts; 4) track and monitor pesticide use; 5) study impacts of managed pollinators; 6) monitor trade and sales of managed pollinators; 6) expand education and alternative practices; and 7) identify and develop incentives and resources.
- Recommendations also include the need to: 1) integrate natural and social sciences into pollinator conservation; 2) apply a common good framework; 3) conduct stakeholder mapping; and 4) evaluate effectiveness of conservation actions.

5.4 Concluding Thoughts

Within the North American context, there are many unknowns regarding pollinators, pollinator population trends, and drivers of change, as reviewed in this report. However, it is clear that the ecological, economic and social foundations of life and society in North America are reliant upon pollination and other ecosystem services. Finding a path forward to ensure conservation of pollinators in North America is therefore crucial to a healthy environment and robust economy. However, a continental approach to pollinator conservation will require the development of policy, science and management in a broad-ranging, visionary and flexible manner.

The distributions of many pollinators extend across political boundaries, and as a result their populations are affected by environmental conditions and human activities in different jurisdictions or countries. Moreover, non-native pollinators and pesticides used for agriculture are often transported across international borders. Therefore, broad-scale pollinator management and conservation are essential. Shared information, tracking of trade and sales, baseline data on native and non-native pollinators, and lessons learned can help address important knowledge gaps that limit the ability for any stakeholder to make conservation decisions for wide-ranging pollinators. It is critical for policymakers and citizens in North America to work, collaborate and share resources and capacity across boundaries in order to inform and effectively implement conservation measures.

This report has reviewed the state of knowledge about pollinator diversity, population trends and drivers of change in North America. It has also summarized exchanges held regionally on the importance and the need to incorporate social sciences and human dimensions into pollinator conservation. Finally, it has provided some recommendations for addressing pollinator conservation on a collaborative basis in North America, highlighting work that can be done to coordinate and improve research and monitoring of pollinator species, as well as recommendations to better integrate human dimensions in pollinator conservation work.

Appendix 1: Quantitative Assessment Methods

As part of the research carried out to prepare this publication, researchers from University of Northern Arizona assembled existing, publicly available records of known or likely pollinators by country, habitat, and ecoregion. They developed a database of likely pollinator genera and retrieved observation records of those genera from the Global Biodiversity Information Facility (GBIF) Home Page. They used existing overviews of pollination in North America to assemble a genus list, including data from Discover Life, the Biosystematic Database of World Diptera, BugGuide.net, and published sources. In some cases, genera may include species that visit flowers and others that do not, but this is often not known for certain (the full dietary breadth of many invertebrate species in particular is unclear). However, they included these genera in order to assess areas and habitats of high pollinator diversity for conservation planning, given that an overestimate of such diversity is more conservative and more likely to lead to positive conservation outcomes than an underestimate.

They developed code to extract occurrence records from GBIF (an international repository for species occurrence data) using R version 3.6.2 (R Core Development Team 2016). GBIF amalgamates information from a variety of sources, including museum specimens and geotagged photographs from citizen science projects, and curating over a trillion species observations. Given the coverage and volume of observations, the GBIF database is an ideal resource to derive information on understudied species with little or no representation in the published literature. Using the package 'rgbif' (Chamberlain et al. 2022), they queried the GBIF database and removed spatially inaccurate data points following standard data cleaning protocol (R-package = 'CoordinateCleaner') (Yesson et al. 2007).

To assess rarity, they extracted data on the spatial distribution, number of observations, observation time horizon, and species within a genus (i.e., as a metric of taxonomic diversity). Observation number and frequency should not be interpreted as a direct measure of abundance, since these metrics conflate abundance and observability given the lack of data regarding survey effort (i.e., tendency for focal taxa to occur near human populations, visibility, size, etc.). However, low rates of occurrence serve to highlight species that warrant further investigation of their ecological status. They also used georeferenced data points to extract information on ecoregion and habitat type from the Ecoregions of North America Level 1 as well as from the North American Land Change Monitoring System Landsat 30m data layers. These location data allowed an examination of relative distributions of pollinator occurrences in order to identify ecoregions and habitats with particularly high pollinator diversity.

Similar coding was used for vertebrate pollinators, but the full pollinator list of known vertebrate nectar-feeders in North America was taken from Aslan et al. (2013) and entered at the species level into the GBIF query system. There were 228 vertebrates in the database, including icterids, picids, tanagers, hummingbirds, and nectar-feeding bats. As for invertebrates, the researchers used the query code to extract observation number and frequency, spatial distribution, observation time horizon, ecoregion, and habitat type for the full list of vertebrates.

Additionally, they used the IUCN Red List, version 3, to extract conservation status for all vertebrates in the database. The IUCN Red List uses expert consensus to assess species worldwide and assign them to threat-level categories including Extinct, Extinct in the Wild, Critically Endangered, Endangered, Vulnerable, Near Threatened, Least Concern, and Data Deficient. Assessments indicate the quantity of population decline or range contraction that has been observed for a particular species or is deemed likely based on current threats to that species.

They assembled the list of the species of conservation concern across the three countries in order to examine the habitats and ecoregions of these species, to permit a discussion of relevant drivers of change in those sites. The IUCN Red List provided an initial list of 11 vertebrate pollinators of conservation concern for North America. Although the IUCN Red List is far less developed for invertebrates than for vertebrates, they also downloaded from the Red List webpage the IUCN conservation status of all invertebrates for the three focal counties. Only 70 such records occurred, consisting of 40 *Coleoptera*, 19 *Hymenoptera*, and 11 *Lepidoptera*. Twenty-five of these invertebrates (35.7 percent) were rated as Near Threatened or in worse status on the Red List.

The IUCN Red List is international in scope and includes input from thousands of scientists; as such, it can be considered the best authority on the status of any species it contained. However, because so few invertebrates have been evaluated on the list, the researchers additionally examined national and state/province-level conservation assessments to seek other pollinator species of conservation concern. At the national level, these assessments included listings by Canada's Committee on the Status of Endangered Wildlife in Canada (COSEWIC), the US Endangered Species Act, and the Mexican Official Norm NOM-059-SEMARNAT-2010 (*Protección ambiental-Especies nativas de México de flora y fauna silvestres*). At the state or province level, these assessments included Canadian province listings (obtained by examining each provincial government website), US state listings (obtained by examining each state government website as well as, when those websites referred to them in their listings, State Wildlife Action Plans), and Mexico's *Estrategias Estatales de Biodiversidad* (https://www.biodiversidad.gob.mx/region/EEB/estrategias.html).

Once the researchers had developed a list of species of conservation concern from these international, national, and state/provincial levels, they applied the GBIF query code to each species in turn to obtain its observation number and frequency, spatial distribution, ecoregion, and habitat type. They then fed all outputs into the database in order to summarize occurrence of threatened species spatially and taxonomically.

In combination, these methods generated the number of records per taxon per geographic area, allowing the researchers to examine the known diversity of pollinators and their occurrence by conservation status across the trinational region. The query coding allowed them to determine which ecoregions and habitat types are particularly high in recorded diversity and also contain particularly high concentrations of threatened species. They allow the examination of the time horizon over which various taxa have been recorded, in order to identify taxa that have experienced a decrease in observations over time. These methods provide a quantitative overview of pollinator occurrence, based on an immense dataset of robust records assembled with rigorous quality control, and including taxa that are rare or absent in the peer-reviewed literature. In combination with the literature-based overview of pollinator trends presented above, this approach provides insights into the state of pollinators of North America, and provides a basis to discuss the relevance of current pollinator declines for ecosystem services, socio-cultural values, biodiversity, and agriculture.

Appendix 2: Global Biodiversity Information Facility Records for Orders of Assumed Insect Pollinators in North America

Table 2. GBIF Records for Orders of Assumed Insect Pollinators in North America

Coleoptera	**No. genera**	***Diptera***	**No. genera**	***Hemiptera***	**No. genera**	***Hymenoptera***	**No. genera**	***Lepidoptera***	**No. genera**
Anthicidae	2	*Acroceridae*	6	*Coreidae*	1	*Andrenidae*	13	*Crambidae*	204
Bruchidae	4	*Agromyzidae*	22	*Lygaeidae*	3	*Apidae*	70	*Erebidae*	2
Buprestidae	3	*Anthomyiidae*	30	*Miridae*	1	*Colletidae*	8	*Gelechiidae*	74
Cantharidae	3	*Apioceridae*	1	*Pentatomidae*	1	*Halictidae*	28	*Geometridae*	237
Carabidae	1	*Asilidae*	104	*Reduviidae*	3	*Megachilidae*	26	*Hesperiidae*	101
Cerambycidae	16	*Bibionidae*	1	*Rhopalidae*	1	*Melittidae*	3	*Lycaenidae*	42
Chrysomelidae	4	*Bombyliidae*	49	*Scutelleridae*	1	*Vespidae*	14	*Noctuidae*	360
Cleridae	1	*Calliphoridae*	19					*Nymphalidae*	61
Coccinellidae	4	*Carnidae*	3					*Papilionidae*	17
Cucujidae	2	*Cecidomyiidae*	2					*Papilionoidea*	1
Curculionidae	6	*Ceratopogonidae*	3					*Pieridae*	12
Dasytidae	1	*Chironomidae*	136					*Prodoxidae*	6
Dermestidae	2	*Chloropidae*	56					*Pterophoridae*	27
Elateridae	1	*Culicidae*	1					*Riodinidae*	6
Lycidae	1	*Dolichopodidae*	52					*Sphingidae*	45
Meloidae	3	*Empididae*	25					*Zygaenidae*	12
Melyridae	2	*Ephydridae*	58						
Mordellidae	3	*Heleomyzidae*	21						
Nitidulidae	35	*Hybotidae*	26						
Oedmeridae	1	*Lauxaniidae*	22						

Coleoptera	**No. genera**	***Diptera***	**No. genera**	***Hemiptera***	**No. genera**	***Hymenoptera***	**No. genera**	***Lepidoptera***	**No. genera**
Phalacridae	1	*Lonchopteridae*	1						
Rhizophagidae	1	*Muscidae*	47						
Scarabaeidae	6	*Mycetophilidae*	1						
Scraptiidae	1	*Nemestrinidae*	3						
Staphylinidae	2	*Opomyzidae*	3						
		Phoridae	32						
		Psychodidae	1						
		Rhagionidae	7						
		Rhinophoridae	3						
		Sarcophagidae	50						
		Scathophagidae	31						
		Scatopsidae	17						
		Sciaridae	35						
		Sciomyzidae	21						
		Sepsidae	7						
		Sphaeroceridae	40						
		Sphecidae	10						
		Syrphidae	65						
		Tabanidae	32						
		Tachinidae	225						
		Tephritidae	48						
		Therevidae	23						
		Tipulidae	14						
Total Coleoptera	**106**	***Total Diptera***	**1353**	***Total Hemiptera***	**11**	***Total Hymenoptera***	**162**	***Total Lepidoptera***	**1207**

Source: University of Northern Arizona Landscape Conservation Initiative, 2021

Bibliography

Abatzoglou, J.T. and C.A. Kolden. 2011. Climate change in western US deserts: Potential for increased wildfire and invasive annual grasses. *Rangeland Ecology & Management* 64(5): 471–478.

Agriculture and Agri-Food Canada. 2014. Native Pollinators and Agriculture in Canada. Ottawa ON: Agriculture and Agri-Food Canada. Available online: http://publications.gc.ca/collections/collection_2014/aac-aafc/A59-12-2014-eng.pdf.

Agriculture and Agri-Food Canada. 2019. Statistical Overview of the Canadian Honey and Bee Industry, 2019. https://agriculture.canada.ca/en/canadas-agriculture-sectors/horticulture/horticulture-sector-reports/statistical-overview-canadian-honey-and-bee-industry-2019. Consulted June 29, 2021.

Aguirre, A. and R. Dirzo. 2008. Effects of fragmentation on pollinator abundance and fruit set of an abundant understory palm in a Mexican tropical forest. *Biological Conservation* 141: 375–384.

Alberta Biodiversity Monitoring Institute. 2018. *Ecosystem services assessment project: Pollination services report*. Edmonton Alberta: Alberta Biodiversity Monitoring Institute. Available online: https://ecosystemservices.abmi.ca/resource/assessing-the-value-of-pollination/.

Allsopp, M.H., W.J. de Lange and R. Veldtman. 2008. Valuing insect pollination services with cost of replacement. *PloS One* 3(9): 3128. https://doi.org/10.1371/journal.pone.0003128

Arita, H.T. and K. Santos-del-Prado. 1999. Conservation biology of nectar-feeding bats in Mexico. *Journal of Mammalogy* 80(1): 31–41. https://doi.org/10.2307/1383205.

Ashworth, L., M. Quesada, A. Casas, R. Aguilar and K. Oyama. 2009. Pollinator-dependent food production in Mexico. *Biological Conservation* 142(5): 1050–1057. https://doi.org/10.1016/j.biocon.2009.01.016.

Aslan, C.E., E.S. Zavaleta, B. Tershy and D. Croll. 2013. Mutualism disruption threatens global plant biodiversity: A systematic review. *PLoS ONE* 8(6): e66993. http://dx.doi.org/10.1371/journal.pone.0066993.

Bahreini, R. and R.W. Currie. 2015. The influence of *Nosema* (*Microspora*: *Nosematidae*) infection on honey bee (*Hymenoptera: Apidae*) defense against *Varroa destructor* (*Mesostigmata*: *varroidae*). *Journal of Invertebrate Pathology* 132: 57–65. https://doi.org/10.1016/j.jip.2015.07.019.

Baxter-Gilbert, J.H., J.L. Riley, C.J.H. Neufeld, J.D. Litzgus and D. Lesbarrères. 2015. Road mortality potentially responsible for billions of pollinating insect deaths annually. *Journal of Insect Conservation* 19: 1029–1035. https://doi.org/10.1007/s10841-015-9808-z.

Bedford, F.E., R.J. Whittaker and J.T. Kerr. 2012. Systemic range shift lags among a pollinator species assemblage following rapid climate change. *Botany* 90(7): 587–597. http://dx.doi.org.proxy.ubishops.ca:2048/10.1139/B2012-052.

Bennett, N. J., R. Roth, S. C. Klain, K. Chan, P. Christie, D. A. Clark, G. Cullman, D. Curran, T. J. Durbin, G. Epstein, A. Greenberg, M. P. Nelson, J. Sandlos, R. Stedman, T. L. Teel, R. Thomas, D. Veríssimo, C. Wyborn. 2017. Conservation social science: Understanding and integrating human dimensions to improve conservation. *Biological Conservation* 205: 93-108.

Bradbear, N. 1988. World distribution of major honeybee diseases and pests. *Bee World* 69(1): 15–39. DOI: 10.1080/0005772X.1988.11098943.

Breed, G.A., S. Stichter and E.E. Crone. 2013. Climate-driven changes in northeastern US butterfly communities. *Nature Climate Change* 3: 142–145. https://doi.org/10.1038/nclimate1663.

Brook, B.W., N.S. Sodhi and C.J.A. Bradshaw. 2008. Synergies among extinction drivers under global change. *Trends in Ecology & Evolution* 23(8): 453–460. https://doi.org/10.1016/j.tree.2008.03.011.

Buchmann, S.L. and G.P. Nabhan. 2012. *The Forgotten Pollinators*. Washington DC: Island Press.

Buermann, W., J.A. Chaves, R. Dudley, J.A. McGuire, T.B. Smith and D.L. Altshuler. 2011. Projected changes in elevational distribution and flight performance of montane Neotropical hummingbirds in response to climate change. *Global Change Biology* 17(4): 1671–1680. https://doi.org/10.1111/j.1365-2486.2010.02330.x.

Burkle, L.A., J.C. Marlin and T.M. Knight. 2013. Plant-pollinator interactions over 120 years: Loss of species, co-occurrence, and function. *Science* 339(6127): 1611–1615. DOI: 10.1126/science.1232728.

Calderone, N.W. 2012. Insect pollinated crops, insect pollinators and US agriculture: Trend analysis of aggregate data for the period 1992–2009. *PLoS ONE* 7(5): e37235. https://doi.org/10.1371/journal.pone.0037235.

Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter and T.L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences* 108(2): 662–667. https://doi.org/10.1073/pnas.1014743108.

Canadian Food Inspection Agency. 2013a. *Alfalfa leaf cutting bee producer guide to the national bee farm-level biosecurity standard*. Consulted online: https://inspection.canada.ca/animal-health/terrestrial-animals/biosecurity/standards-and-principles/alfalfa-leaf-cutting-bee/eng/1379967333142/1380030729469?chap=0.

Canadian Food Inspection Agency. 2013b. *Bumblebee sector guide to the national bee farm-level biosecurity standard*. Consulted online: https://inspection.canada.ca/animal-health/terrestrial-animals/biosecurity/standards-and-principles/bumblebee-sector-guide/eng/1378396751545/1378397236948?chap=0.

Canadian Honey Council. 2018. Industry Overview – Canadian Apiculture Industry. https://honeycouncil.ca/archive/honey_industry_overview.php. Consulted on June 28, 2021.

Cane, J.H., R.L. Minckley, L.J. Kervin, T.H. Roulston and N.M. Williams. 2006. Complex responses within a desert bee guild (*Hymenoptera: Apiformes*) to urban habitat fragmentation. *Ecological Applications* 16(2): 632–644. https://doi.org/10.1890/1051-0761(2006)016[0632:CRWADB]2.0.CO;2.

Casas, A. and F. Parra 2007. Agrobiodiversidad, parientes silvestres y cultura. *LEISA Revista de Agroecologia* 23(2): 5–8. https://www.leisa-al.org/web/index.php/volumen-23-numero-2/1799-agrobiodiversidad-parientes-silvestres-y-cultura.

Castañeda-Vildózola, A., A. Equihua-Martínez,, J. Valdés-Carrasco, A.F. Barrientos-Priego, G. Ish-Am and S. Gazit. 1999. Insectos polinizadores del aguacatero en los estados de México y Michoacán. *Revista Chapingo Serie Horticultura* 5: 129–136. Available online: http://avocadosource.com/WAC4/WAC4_p129.pdf.

CEC. 1997. *Ecological Regions of North America: Toward a Common Perspective*. Montreal, Quebec: Commission for Environmental Cooperation. Available online: http://www3.cec.org/islandora/en/item/1701-ecological-regions-north-america-toward-common-perspective-en.pdf.

CEC. 2015. Land Cover 30m, 2015 (Landsat and RapidEye). Available online: http://www.cec.org/north-american-environmental-atlas/land-cover-30m-2015-landsat-and-rapideye/.

CEC. 2023. *Strategic Plan 2021–2025: Renewing our trilateral commitment and implementing the new Free Trade Agreement and its supporting Environmental Cooperation Agreement.* Montreal, Quebec: Commission for Environmental Cooperation. Available online: http://www.cec.org/files/documents/strategic_plans/cec-strategic-plan-2021-2025.pdf. Consulted on 4 May 2023.

Chamberlain S, Barve V, Mcglinn D, Oldoni D, Desmet P, Geffert L, Ram K. 2022. *rgbif: Interface to the Global Biodiversity Information Facility API*. R package version 3.7.2. https://cran.r-project.org/package=rgbif

Colla, S.R., F. Gadallah, L. Richardson, D. Wagner and L. Gall. 2012. Assessing declines of North American bumble bees (*Bombus* spp.) using museum specimens. *Biodiversity and Conservation* 21: 3585–3595. https://doi.org/10.1007/s10531-012-0383-2

Contreras-Escareño, F., C. Echazarreta, B. Pérez-Armendáriz, J. Cavazos Arroyo, J.). Macías-Macías and J.M. Tapia-González. 2016. Beekeeping in Jalisco, Mexico. In *Beekeeping and Bee Conservation - Advances in Research*, E.D. Chambó, ed. London: IntechOpen. https://www.intechopen.com/books/beekeeping-and-bee-conservation-advances-in-research/beekeeping-in-jalisco-m-xico.

Cutler, G.C., V.O. Nams, P. Craig, J.M. Sproule and C. Sheffield. 2015. Wild bee pollinator communities of lowbush blueberry fields: Spatial and temporal trends. *Basic and Applied Ecology* 16(1): 73–85. https://doi.org/10.1016/j.baae.2014.11.005.

Daily, G.C. 1997. Introduction: What are ecosystem services? In *Nature's services: societal dependence on natural ecosystems*, G.C. Daily, ed., 1-11. Washington DC: Island Press.

Dalsgaard, B. K. Trøjelsgaard, A. M. Martín González, D. Nogués-Bravo, J. Ollerton, T. Petanidou, B. Sandel, M. Schleuning, Z. Wang, C.Rahbek, W.J. Sutherland, J-C. Svenning and J.M. Olesen. 2013. Historical climate-change influences modularity and nestedness of pollination networks. *Ecography* 36: 1331–1340. doi: 10.1111/j.1600-0587.2013.00201.x.

Dicks, L.V., B. Viana, R. Bommarco, B. Brosi, M. del Coro Arizmendi,, S.A. Cunningham, L. Galetto, R. Hill, A.V. Lopes, C. Pires and H. Taki. 2016. Ten policies for pollinators. *Science* 354(6315): 975–976. DOI: 10.1126/science.aai9226.

Dicks, L.V., T.D. Breeze, H.T. Ngo, D. Senapathi, J. An et al. 2021. A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nat Ecol Evol* 5: 1453–1461. https://doi.org/10.1038/s41559-021-01534-9

Didham, R.K., Y. Basset, C.M. Collins, S.R. Leather, N.A. Littlewood, M.H.M. Menz, J. Müller, L. Packer, M.E. Saunders, K. Schönrogge, A.J.A. Stewart, S.P. Yanoviak and C. Hassall. 2020. Interpreting insect declines: seven challenges and a way forward. *Insect Conservation and Diversity* 13: 103–114. https://doi.org/10.1111/icad.12408.

Douglas, M.R., D.B. Sponsler, E.V. Lonsdorf and C.M. Grozinger. 2020. County-level analysis reveals a rapidly shifting landscape of insecticide hazard to honey bees (*Apis mellifera*) on US farmland. *Scientific Reports* 10, 797. https://doi.org/10.1038/s41598-019-57225-w.

Drewitt,A.L. and R.H.W. Langston. 2006. Assessing the impacts of wind farms on birds. *Ibis* 148: 29–42. https://doi.org/10.1111/j.1474-919X.2006.00516.x.

Ebersole, R. 2018. Inside the black market hummingbird love charm trade. <https://www.nationalgeographic.com/news/2018/04/wildlife-watch-illegal-hummingbird-trade-love-charm-mexico-witchcraft/>. Consulted June 22, 2021.

Encarnação, J., M.A. Teodósio and P. Morais. 2021. Citizen science and biological invasions: A review. *Frontiers in Environmental Science* 8:303. https://doi.org/10.3389/fenvs.2020.602980.

Everitt, J.C., J. Welsted and C. Stadel. 1996. *The Geography of Manitoba: its Land and Its People*. Winnipeg: University of Manitoba Press.

Food and Agriculture Organization. 2008. *Rapid assessment of pollinators' status: A contribution to the international initiative for the conservation and sustainable use of pollinators*. Rome Italy: Food and Agriculture Organization of the United Nations. Available online: http://www.fao.org/3/i1046e/i1046e.pdf.

Food and Agriculture Organization. 2009. *Los polinizadores: Su biodiversidad poco apreciada, pero importante para la alimentación y la agricultura*. Tratado internacional sobre los recursos fitogenéticos para la alimentación y la agricultura. Food and Agriculture Organization of the United Nations. Available online: http://www.fao.org/3/be104s/be104s.pdf.

Forister, M.L., B. Cousens, J.G. Harrison, K. Anderson, J.H. Thorne, D. Waetjen, C.C. Nice, M. De Parsia, M.L. Hladik, R. Meese, H. van Vliet and A.M. Shapiro. 2016. Increasing neonicotinoid use and the declining butterfly fauna of lowland California. *Biology Letters* 12: 20160475. 20160475. https://doi.org/10.1098/rsbl.2016.0475.

Fox, R. 2013. The decline of moths in Great Britain: a review of possible causes. *Insect Conservation and Diversity* 6(1): 5–19. https://doi.org/10.1111/j.1752-4598.2012.00186.x.

Freitas, B.M., V.L. Imperatriz-Fonseca, L.M. Medina, A.D.M.P. Kleinert, L. Galetto, G. Nates-Parra and J.J.G. Quezada-Euán. 2009. Diversity, threats and conservation of native bees in the Neotropics. *Apidologie* 40: 332–346. https://doi.org/10.1051/apido/2009012.

Fuentes-Ramirez, A., J.W. Veldman, C. Holzapfel and K.A. Moloney. 2016. Spreaders, igniters, and burning shrubs: plant flammability explains novel fire dynamics in grass-invaded deserts. *Ecological Applications* 26(7): 2311-2322. https://doi.org/10.1002/eap.1371.

Gilgert, W. and M. Vaughan 2011. The value of pollinators and pollinator habitat to rangelands: Connections among pollinators, insects, plant communities, fish, and wildlife. *Rangelands* 33(3): 14–19. https://doi.org/10.2111/1551-501X-33.3.14.

Gill, R.J., K.C.R. Baldock., M.J.F. Brown., J. E. Cresswell., L.V. Dicks, M.T. Fountain, M.P.D. Garratt, L.A. Gough, M.S. Heard, J.M. Holland, J. Ollerton, G.N. Stone, C.Q. Tang, A.J. Vanbergen, A.P. Vogler, G. Woodward, A.N. Arce, N.D. Boatman, R. Brand-Hardy, T.D. Breeze, M. Green, C.M. Hartfield, R.S. O'Connor, J.L. Osborne, J. Phillips, P.B. Sutton and S.G. Potts. 2016. Chapter Four - Protecting an ecosystem service: Approaches to understanding and mitigating threats to wild insect pollinators. *Advances in Ecological Research*, Part 2, Vol. 54, G. Woodward and D. A. Bohan, eds., 135–206. Academic Press. https://doi.org/10.1016/bs.aecr.2015.10.007.

Gray, M.E., B.G. Dickson and L.J. Zachmann. 2014. Modelling and mapping dynamic variability in large fire probability in the lower Sonoran Desert of southwestern Arizona. *International Journal of Wildland Fire* 23(8): 1108–1118.

Graystock, P., E.J. Blane, Q.S. McFrederick, D. Goulson and W.O.H. Hughes. 2016. Do managed bees drive parasite spread and emergence in wild bees? *International Journal for Parasitology: Parasites and Wildlife* 5(1): 64–75. https://doi.org/10.1016/j.ijppaw.2015.10.001.

Greenleaf, S.S., N.M. Williams, R. Winfree et al. 2007. Bee foraging ranges and their relationship to body size. *Oecologia* 153: 589–596. https://doi.org/10.1007/s00442-007-0752-9

Hall, D.M. and D.J. Martins. 2020. Human dimensions of insect pollinator conservation. *Current Opinion in Insect Science* 38: 107–114. https://doi.org/10.1016/j.cois.2020.04.001.

Hall, P.W. 2009. *Sentinels on the wing: The status and conservation of butterflies in Canada*. Ottawa: NatureServe Canada. Available online: https://www.natureserve.org/sites/default/files/publications/files/natureserve_canada_-_hall_sentinels_on_the_wing_2009.pdf.

Hallmann, C.A., M. Sorg, E. Jongejans, H. Siepel, N. Hofland, H. Schwan, W. Stenmans, A. Müller, H. Sumser, T. Hörren, and D. Goulson. 2017. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PLoS ONE* 12(10): e0185809. https://doi.org/10.1371/journal.pone.0185809.

Hammerson, G.A., M. Kling, M. Harkness, M. Ormes and B.E. Young. 2017. Strong geographic and temporal patterns in conservation status of North American bats. *Biological Conservation* 212, Part A: 144–152. https://doi.org/10.1016/j.biocon.2017.05.025.

Hanula, J.L., M.D. Ulyshen and S. Horn. 2016. Conserving pollinators in North American forests: a review. *Natural Areas Journal* 36(4): 427–439. https://doi.org/10.3375/043.036.0409.

Havstad, K., D. Peters, B. Allen-Diaz, J. Bartolome, B. Bestelmeyer, D. Briske, J. Brown, M. Brunson, J. Herrick, L. Huntsinger, P. Johnson, L. Joyce, R. Pieper, T. Svejcar, and J. Yao. 2009. The Western United States rangelands: A major resource. In: *Grasslands: Quietness and Strength for a New American Agriculture*, W.F. Wedin, and S.L. Fales, ed., 75-93. Madison, WI, USA: American Society of Agronomy, Inc. Crop Science Society of America, Inc. Soil Science Society of America, Inc. https://doi.org/10.2134/2009.grassland.c5

Hedtke, S.M., E.J. Blitzer, G.A. Montgomery and B.N. Danforth. 2015. Introduction of non-native pollinators can lead to transcontinental movement of bee-associated fungi. *PLoS ONE* 10(6): e0130560. https://doi.org/10.1371/journal.pone.0130560.

Hernández, D.L., D.M. Vallano, E.S. Zavaleta, Z. Tzankova, J.R. Pasari, S. Weiss, P.C. Selmants and C. Morozumi. 2016. Nitrogen pollution is linked to US listed species declines. *BioScience* 66(3): 213–222. https://doi.org/10.1093/biosci/biw003.

Hernandez, R.R., A. Armstrong, J. Burney, G. Ryan, K. Moore-O'Leary, I. Diédhiou, S.M. Grodsky, L. Saul-Gershenz, R. Davis, J. Macknick, D. Mulvaney, G.A. Heath, S.B. Easter, M.K. Hoffacker, M.F. Allen and D.M. Kammen. 2019. Techno–ecological synergies of solar energy for global sustainability. *Nature Sustainability* 2: 560–568. https://doi.org/10.1038/s41893-019-0309-z.

Herrerias-Diego, Y., M. Quesada, K.E. Stoner and J.A. Lobo. 2006. Effects of forest fragmentation on phenological patterns and reproductive success of the tropical dry forest tree *Ceiba aesculifolia*. *Conservation Biology* 20(4): 1111–1120. https://doi.org/10.1111/j.1523-1739.2006.00370.x.

Horth, L. and L.A. Campbell. 2018. Supplementing small farms with native mason bees increases strawberry size and growth rate. *Journal of Applied Ecology* 55: 591–599. https://doi.org/10.1111/1365-2664.12988.

Inamine, H., S.P. Ellner, J.P. Springer and A.A. Agrawal. 2016. Linking the continental migratory cycle of the monarch butterfly to understand its population decline. *Oikos* 125:1081–1091. doi: 10.1111/oik.03196.

IPBES. 2016. *The Assessment Report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on Pollinators, Pollination and Food Production*. S.G. Potts, V. L. Imperatriz-Fonseca, and H. T. Ngo (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 552 pages. https://doi.org/10.5281/zenodo.3402856.

Isaacs, R. and A.K. Kirk. 2010. Pollination services provided to small and large highbush blueberry fields by wild and managed bees. *Journal of Applied Ecology* 47(4): 841–849. https://doi.org/10.1111/j.1365-2664.2010.01823.x.

Janzen, D.H. and W. Hallwachs. 2019. Perspective: where might be many tropical insects? *Biological Conservation* 233: 102-108. https://doi.org/10.1016/j.biocon.2019.02.030.

Jia, X., B. Bai, J. Zhang and Y. Huang. 2018. The effects of IPBES deliverables on global biodiversity conservation strategy—an analysis based on the U. S. pollinator protection policy. *Biodiversity Science* 26(5): 527–534. https://doi.org/10.17520/biods.2017323.

Jinbo, U., T. Kato and M. Ito. 2011. Current progress in DNA barcoding and future implications for entomology. *Entomological Science* 14(2): 107–124. https://doi.org/10.1111/j.1479-8298.2011.00449.x.

Johnson, S.D. and K.E. Steiner. 2000. Generalization versus specialization in plant pollination systems. *Trends in Ecology & Evolution* 15(4): 140–143. https://doi.org/10.1016/S0169-5347(99)01811-X.

Jose, S. Agroforestry for conserving and enhancing biodiversity. *Agroforest Syst* 85: 1–8 (2012). https://doi.org/10.1007/s10457-012-9517-5

Kadri, S.M., B.A. Harpur, R.O. Orsi and A. Zayed. 2016. A variant reference data set for the Africanized honeybee, *Apis mellifera*. *Scientific Data* 3,160097. https://doi.org/10.1038/sdata.2016.97.

Kardol, P. and D.A. Wardle. 2010. How understanding aboveground–belowground linkages can assist restoration ecology. *Trends in Ecology & Evolution* 25(11): 670–679. https://doi.org/10.1016/j.tree.2010.09.001.

Kay, S., E. Kühn, M. Albrecht, L. Sutter, E. Szerencsits and F. Herzog. 2020. Agroforestry can enhance foraging and nesting resources for pollinators with focus on solitary bees at the landscape scale. *Agroforestry Systems* 94(2): 379–387. https://doi.org/10.1007/s10457-019-00400-9.

Keilsohn, W., D.L. Narango and D.W. Tallamy. 2018. Roadside habitat impacts insect traffic mortality. *Journal of Insect Conservation* 22(2): 183–188. https://doi.org/10.1007/s10841-018-0051-2.

Kennedy, C.M., E. Lonsdorf, M.C. Neel, N.M. Williams, T.H. Ricketts, R. Winfree, R. Bommarco, C. Brittain, A.L. Burley, D. Cariveau, L.G. Carvalheiro, N.P. Chacoff, S.A. Cunningham, B.N. Danforth, J-H. Dudenhöffer, E. Elle, H.R. Gaines, L.A. Garibaldi, C. Gratton, A. Holzschuh, R. Isaacs, S.K. Javorek, S. Jha, A. M. Klein, K. Krewenka, Y. Mandelik, M.M. Mayfield, L. Morandin, L.A. Neame,

M. Otieno, M. Park, S.G. Potts, M. Rundlöf, A. Saez, I. Steffan-Dewenter, H. Taki, B. Felipe Viana, C. Westphal, J.K. Wilson, S.S. Greenleaf, and C. Kremen. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology Letters* 16: 584–599. https://doi.org/10.1111/ele.12082.

Kennedy, J. and R. Arghiris. 2019. *House of the Royal Lady Bee: Maya revive native bees and ancient beekeeping*. Mongabay. https://news.mongabay.com/2019/01/house-of-the-royal-lady-bee-maya-revive-native-bees-and-ancient-beekeeping/. Consulted June 28, 2021.

Kerr, J.T. 2001. Butterfly species richness patterns in Canada: Energy, heterogeneity, and the potential consequences of climate change. *Conservation Ecology* 5(1), 13pp. https://www.jstor.org/stable/26271787

Klein, S., A. Cabirol, J.M. Devaud, A.B. Barron and M. Lihoreau. 2017. Why bees are so vulnerable to environmental stressors. *Trends in Ecology & Evolution* 32(4): 268–278. https://doi.org/10.1016/j.tree.2016.12.009.

Koh, I., E,V, Lonsdorf, N.M. Williams, C. Brittain,, R. Isaacs, J. Gibbs and T.H. Ricketts. 2016. Modeling the status, trends, and impacts of wild bee abundance in the United States. *Proceedings of the National Academy of Sciences* 113(1): 140–145. https://doi.org/10.1073/pnas.1517685113.

Köhler, H-R. and R. Triebskorn. 2013. Wildlife ecotoxicology of pesticides: can we track effects to the population level and beyond? *Science* 341(6147): 759–765. DOI: 10.1126/science.1237591.

Kopec, K. and L.A. Burd. 2017. *Pollinators in Peril: A Systematic Review of North American and Hawaiian native bees*. Tucson, Arizona: Center for Biological Diversity. https://biologicaldiversity.org/campaigns/native_pollinators/pdfs/Pollinators_in_Peril.pdf.

Kuyah, S., I. Öborn and M. Jonsson. 2017. Regulating ecosystem services delivered in agroforestry systems. In *Agroforestry: Anecdotal to modern science*, J.C. Dagar and V.P. Tewari, ed., 797–815. Singapore: Springer. DOI: 10.1007/978-981-10-7650-3_33.

Lambe, C.M., 2018. What's all the buzz about? Analyzing the decision to list the rusty patched bumblebee on the Endangered Species List comments. *Villanova Environmental Law Journal* 29(1): 129–154. Available at: https://digitalcommons.law.villanova.edu/elj/vol29/iss1/5.

Landaverde-González, P., J.J.G. Quezada-Euán, P. Theodorou, T.E. Murray, M. Husemann, R. Ayala H. Moo-Valle, R. Vandame and R.J. Paxton. 2017. Sweat bees on hot chillies: provision of pollination services by native bees in traditional slash-and-burn agriculture in the Yucatán Peninsula of tropical Mexico. *Journal of Applied Ecology* 54: 1814–1824. https://doi.org/10.1111/1365-2664.12860.

Langor, D.W., E. K. Cameron, C.J.K. MacQuarrie, A. McBeath, A. McClay, B. Peter, M. Pybus, , T. Ramsfield, K. Ryall, T. Scarr, D. Yemshanov, I. DeMerchant, R. Foottit, and G.R. Pohl. 2014. Non-native species in Canada's boreal zone: diversity, impacts, and risk. *Environmental Reviews* 22: 372–420. https://doi.org/10.1139/er-2013-0083.

Larson, E.R., B. M Graham, R. Achury, J.J. Coon, M.K. Daniels, D.K. Gambrell, K.L. Jonasen, G.D. King, N. LaRacuente, T.I.N. Perrin-Stowe, E.M. Reed, C.J. Rice, S.A. Ruzi, M.W. Thairu, J.C. Wilson and A.V. Suarez. 2020. From eDNA to citizen science: emerging tools for the early detection of invasive species. *Frontiers in Ecology and the Environment* 18(4): 194–202. https://doi.org/10.1002/fee.2162.

Lázaro, A., T. Tscheulin, J. Devalez, G. Nakas and T. Petanidou. 2016a. Effects of grazing intensity on pollinator abundance and diversity, and on pollination services. *Ecological Entomology* 41: 400–412. https://doi.org/10.1111/een.12310.

Lázaro, A, T. Tscheulin, J. Devalez, G. Nakas, A. Stefanaki, E. Hanlidou and T. Petanidou. 2016b. Moderation is best: effects of grazing intensity on plant–flower visitor networks in Mediterranean communities. *Ecological Applications* 26(3): 796–807. https://doi.org/10.1890/15-0202.

Leather, S.R. 2017. "Ecological Armageddon" more evidence for the drastic decline in insect numbers. *Annals of Applied Biology* 172(1): 1–3. https://doi.org/10.1111/aab.12410.

LeBuhn, G., S. Droege, E.F. Connor, B. Gemmill-Herren, S.G. Potts, R.L. Minckley, T. Griswold, R. Jean, E. Kula, D.W. Roubik, J. Cane, K.W. Wright, G. Frankie and F. Parker. 2013. Detecting insect pollinator declines on regional and global scales. *Conservation Biology* 27(1): 113–120. https://doi.org/10.1111/j.1523-1739.2012.01962.x.

Le Conte, Y. and M. Navajas. 2008. Climate change: impact on honey bee populations and diseases. *Revue scientifique et technique (International Office of Epizootics)* 27(2): 485–97, 499–510. Available online: https://www.vtfarmtoplate.com/assets/resources/files/Climate%20Change_Honey%20Bees.pdf

Lintott, P.R., S.M. Richardson, D.J. Hosken, S.A. Fensome and F. Mathews. 2016. Ecological impact assessments fail to reduce risk of bat casualties at wind farms. *Current Biology* 26(1): R1135–R1136. https://doi.org/10.1016/j.cub.2016.10.003.

Love, B.G. and J.H. Cane. 2019. Mortality and flowering of great basin perennial forbs after experimental burning: implications for wild bees. *Rangeland Ecology & Management* 72(2): 310–317.

Mace, G.M., K. Norris and A.H. Fitter. 2012. Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology & Evolution* 27(1): 19–26. https://doi.org/10.1016/j.tree.2011.08.006.

MacInnis, G. and J.R.K. Forrest. 2019. Pollination by wild bees yields larger strawberries than pollination by honey bees. *Journal of Applied Ecology* 56(4): 824–832. https://doi.org/10.1111/1365-2664.13344.

Maher, S.P., A.M. Kramer, J.T. Pulliam, M.A. Zokan, S.E. Bowden, H.D. Barton, K. Magori and J.M. Drake. 2012. Spread of white-nose syndrome on a network regulated by geography and climate. *Nature Communications* 3,1306. https://doi.org/10.1038/ncomms2301.

Marques, A.T., H. Batalha, S. Rodrigues, H. Costa, M.J.R. Pereira, C. Fonseca, M. Mascarenhas and J. Bernardino. 2014. Understanding bird collisions at wind farms: An updated review on the causes and possible mitigation strategies. *Biological Conservation* 179: 40–52.

Martin-Culma N.Y. and N.A. Arenas-Suárez. 2018. Daño colateral en abejas por la exposición a pesticidas de uso agrícola. *Entramado* 14: 232–240. http://www.scielo.org.co/pdf/entra/v14n1/1900-3803-entra-14-01-232.pdf.

Mathiasson, M.E. and S.M. Rehan. 2019. Status changes in the wild bees of north-eastern North America over 125 years revealed through museum specimens. *Insect Conservation and Diversity* 12(4): 278–288. https://doi.org/10.1111/icad.12347.

McDonald, C.J., and G.R. McPherson. 2013. Creating hotter fires in the Sonoran Desert: buffelgrass produces copious fuels and high fire temperatures. *Fire Ecology* 9: 26–39. https://doi.org/10.4996/fireecology.0902026.

McFrederick, Q.S., J.C. Kathilankal and J.D. Fuentes. 2008. Air pollution modifies floral scent trails. *Atmospheric Environment* 42(10): 2336–2348. https://doi.org/10.1016/j.atmosenv.2007.12.033.

McKechnie, I.M., C.J.M. Thomsen and R.D. Sargent. 2017. Forested field edges support a greater diversity of wild pollinators in lowbush blueberry (*Vaccinium angustifolium*). *Agriculture, Ecosystems & Environment* 237: 154–161. https://doi.org/10.1016/j.agee.2016.12.005.

MEA (Millennium Ecosystem Assessment). 2005. *Ecosystems and Human Well-being: Synthesis Report*. Island Press, Washington, DC. https://www.millenniumassessment.org/documents/document.356.aspx.pdf.

Melhim, A., A. Weersink, Z. Daly and N. Bennett. 2010. *Beekeeping in Canada: Honey and Pollination Outlook*. Canadian Pollination Initiative, Food, Agriculture and Resource Economics. http://www.uoguelph.ca/canpolin/Publications/Outlook-Beekeeping-CANPOLIN06.pdf.

Meeus, I., M.J.F. Brown, D.C. De Graaf, and G. Smagghe. 2011. Effects of invasive parasites on bumble bee declines. *Conservation Biology* 25(4): 662–671. https://www.jstor.org/stable/27976525.

Michener, C.D. 2000. *The Bees of the World*. Baltimore Maryland: John Hopkins University Press.

Mitchell, M.G.E., E.M. Bennett and A. Gonzalez. 2013. Linking landscape connectivity and ecosystem service provision: current knowledge and research gaps. *Ecosystems* 16: 894–908. https://doi.org/10.1007/s10021-013-9647-2.

Moisan-DeSerres, J., M. Chagnon and V. Fournier. 2015. Influence of windbreaks and forest borders on abundance and species richness of native pollinators in lowbush blueberry fields in Québec, Canada. *The Canadian Entomologist* 147: 432–442. doi:10.4039/tce.2014.55.

Moisett, B. and S. Buchmann. 2011. *Bee basics: An introduction to our native bees*. USDA Forest Service and Pollinator Partnership. Available online: https://www.fs.fed.us/wildflowers/pollinators/documents/BeeBasics.pdf.

Montgomery, G.A., R.R. Dunn, R. Fox, E. Jongejans, S.R. Leather, M.E. Saunders, C.R. Shortall, M.W. Tingley and D.L. Wagner. 2020. Is the insect apocalypse upon us? How to find out. *Biological Conservation* 241: 108327. https://doi.org/10.1016/j.biocon.2019.108327.

Morandin, L.A. and M.L. Winston. 2005. Wild bee abundance and seed production in conventional, organic, and genetically modified canola. *Ecological Applications* 15(3): 871–881. https://doi.org/10.1890/03-5271.

Moroń, D., I.M. Grześ, P. Skórka, H. Szentgyörgyi, R. Laskowski, S.G. Potts and M. Woyciechowsk. 2012. Abundance and diversity of wild bees along gradients of heavy metal pollution. *Journal of Applied Ecology* 49(1): 118–125. https://doi.org/10.1111/j.1365-2664.2011.02079.x.

Moroń, D., H. Szentgyörgyi, P. Skórka, S.G. Potts and M. Woyciechowski. 2014. Survival, reproduction and population growth of the bee pollinator, *Osmia rufa* (*Hymenoptera: Megachilidae*), along gradients of heavy metal pollution. *Insect Conservation and Diversity* 7(2): 113–121. https://doi.org/10.1111/icad.12040.

Nakao, F. 2017. Intergovernmental platform on biodiversity and ecosystem services (IPBES): progress and challenges. *Journal of Rural Planning Association* 36(1): 13–16. https://doi.org/10.2750/arp.36.13.

Nanetti, A., L. Bortolotti and G. Cilia. 2021. Pathogens spillover from honey bees to other arthropods. *Pathogens* 10(8): 1044. 10.3390/pathogens10081044

National Research Council. 2007. *Status of Pollinators in North America*. Washington, DC: The National Academies of Science Press. https://doi.org/10.17226/11761.

Nearman, A. and D. van Engelsdorp. 2019. What happened to colony collapse disorder? *Berliner und Munchener Tierarztliche Wochenschrift* 132: 10–15. https://www.vetline.de/what-happened-to-colony-collapse-disorder

Nieto, G. 2011. *Protecting Native Bee Populations in Mexico.* https://ourworld.unu.edu/en/protecting-native-bee-populations-in-mexico. Consulted June 28, 2021.

O'Hara, J.E. and D.M. Wood. 2004. Catalogue of the *Tachinidae* (*Diptera*) of America north of Mexico. *Memoirs on Entomology, International* 18: iv + 410 pp.

Olesen, J.M. and A. Valido. 2003. Lizards as pollinators and seed dispersers: an island phenomenon. *Trends in Ecology & Evolution* 18: 177–181. https://doi.org/10.1016/S0169-5347(03)00004-1.

Ollerton J. 2017. Pollinator diversity: Distribution, ecological function, and conservation. *Annual Review of Ecology, Evolution, and Systematics* 48: 353–376. https://doi.org/10.1146/annurev-ecolsys-110316-022919.

Ontario Ministry of Agriculture, Food, and Rural Affairs. 2018. *2018 Ontario Apiculture Winter Loss Survey*. Consulted online: http://www.omafra.gov.on.ca/english/food/inspection/bees/2018winterloss.htm.

O'Shea, T.J., P.M. Cryan, D.T.S. Hayman, R.K. Plowright and D.G. Streicker. 2016. Multiple mortality events in bats: a global review. *Mammal Review* 46(3): 175–190. https://doi.org/10.1111/mam.12064.

Paini, D.R. 2004. Impact of the introduced honey bee (*Apis mellifera*) (*Hymenoptera: Apidae*) on native bees: A review. *Austral Ecology* 29(4): 399–407. https://doi.org/10.1111/j.1442-9993.2004.01376.x.

Paudel, Y.P., R. Mackereth, R. Hanley and W. Qin. 2015. Honey Bees (*Apis mellifera* L.) and pollination issues: Current status, impacts and potential drivers of decline. *Journal of Agricultural Science* 7(6): 93-109. http://www.ccsenet.org/journal/index.php/jas/article/download/46259/26160.

Pelton, E.M., C.B. Schultz, S.J. Jepsen, S.H. Black and E.E. Crone. 2019. Western monarch population plummets: status, probable causes, and recommended conservation actions. *Frontiers in Ecology and Evolution* 7: 258. https://doi.org/10.3389/fevo.2019.00258.

Pinkus-Rendon, M.A., V. Parra-Tabla and V. Meléndez-Ramírez. 2005. Floral resource use and interactions between *Apis mellifera* and native bees in cucurbit crops in Yucatán, México. *The Canadian Entomologist* 137(4): 441-449. doi:10.4039/n04-043.

Pohl, G.R., J.-F. Landry, B.C. Schmidt, J.D. Lafontaine, J.T. Troubridge, A.D. Macaulay, E.J. van Nieukerken, J.R. deWaard, J.J. Dombroskie, J. Klymko, V. Nazari and K. Stead. 2018. Annotated

Checklist of the Moths and Butterflies (*Lepidoptera*) of Canada and Alaska. Sofia, Bulgaria: Pensoft. Available online: https://ebooks.pensoft.net/books/13080.

Pohl, G.R., J-F. Landry, B.C. Schmidt and J.R. deWaard. 2019. *Lepidoptera* of Canada. *ZooKeys* 24 (819):463–505. doi: 10.3897/zookeys.819.27259.

Pollinator Health Task Force. 2015a. Pollinator Research Action Plan: Report of the Pollinator Health Task Force. Washington DC: White House. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/Pollinator%20Research%20Action%20Plan%202015.pdf.

Pollinator Health Task Force. 2015b. National Strategy to Promote the Health of Honey Bees and Other Pollinators. Washington DC: White House. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/Pollinator%20Health%20Strategy%202015.pdf.

Potts, S.G., J.C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger and W.E. Kunin. 2010. Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution* 25(6): 345–353. https://doi.org/10.1016/j.tree.2010.01.007.

Pustkowiak, S., W. Banaszak-Cibicka, L.E. Mielczarek, P. Tryjanowski and P. Skórka. 2018. The association of windmills with conservation of pollinating insects and wild plants in homogeneous farmland of western Poland. *Environmental Science and Pollution Research* 25(7): 6273–6284. https://doi.org/10.1007/s11356-017-0864-7.

Put, J.E., G.W. Mitchell and L. Fahrig. 2018. Higher bat and prey abundance at organic than conventional soybean fields. *Biological Conservation* 226: 177–185. https://doi.org/10.1016/j.biocon.2018.06.021.

Regal, P.J. 1982. Pollination by wind and animals: Ecology of geographic patterns. *Annual Review of Ecology and Systematics* 13: 497–524. https://www.annualreviews.org/doi/pdf/10.1146/annurev.es.13.110182.002433.

Rhoda, R. and T. Burton. 2010. *Geo-Mexico: the Geography and Dynamics of Modern Mexico*. Ladysmith BC: Sombrero Books.

Richards, K.W. and P.G. Kevan. 2002. Aspects of bee biodiversity, crop pollination, and conservation in Canada. In *Pollinating Bees: the Conservation Link between Agriculture and Nature*, P. Kevan and V.L. Imperatriz-Fonseca, ed., 51-67. Brasilia: Ministry of Environment.

Romero, M.J. and J.J.G. Quezada-Euán. 2013. Pollinators in biofuel agricultural systems: the diversity and performance of bees (*Hymenoptera: Apoidea*) on *Jatropha curcas* in Mexico. *Apidologie* 44: 419–429. https://doi.org/10.1007/s13592-013-0193-x.

Rundlöf, M., G.K.S. Andersson, R. Bommarco, I. Fries, V. Hederström, L. Herbertsson, B.K. Klatt, T.R. Pedersen, J. Yourstone and H.G. Smith. 2015. Seed coating with a neonicotinoid insecticide negatively affects wild bees. *Nature* 521: 77–80. https://doi.org/10.1038/nature14420.

Russo, L. 2016. Positive and negative impacts of non-native bee species around the world. *Insects* 7(4): 69. https://doi.org/10.3390/insects7040069.

Sachman-Ruiz, B., V. Narváez-Padilla and E. Reynaud. 2015. Commercial *Bombus impatiens* as reservoirs of emerging infectious diseases in central Mexico. *Biological Invasions* 17: 2043-2053. https://doi.org/10.1007/s10530-015-0859-6

Sánchez-Bayo, F. and K.A.G. Wyckhuys. 2019. Worldwide decline of the entomofauna: A review of its drivers. *Biological Conservation* 232: 8–27. https://doi.org/10.1016/j.biocon.2019.01.020.

Schweitzer, D.F., N.A. Capuano, B.E. Young BE and S.R. Colla. 2012. *Conservation and Management of North American Bumble Bees*. Washington DC and Arlington VA: USDA Forest Service and NatureServe. Available online: https://www.fs.fed.us/wildflowers/pollinators/documents/ConsMgmtNABumbleBees.pdf.

Semmens, B.X., D.J. Semmens, W.E. Thogmartin, R. Wiederholt, L. López-Hoffman, J.E. Diffendorfer, J.M. Pleasants, K.S. Oberhauser and O.R. Taylor. 2016. Quasi-extinction risk and population targets for the Eastern, migratory population of monarch butterflies (*Danaus plexippus*). *Scientific Reports* 6: 1–7. https://doi.org/10.1038/srep23265.

Sheffield, C.S., P.G. Kevan, S.M. Westby and R.F. Smith. 2008. Diversity of cavity-nesting bees (*Hymenoptera: Apoidea*) within apple orchards and wild habitats in the Annapolis Valley, Nova Scotia, Canada. *The Canadian Entomologist* 140(2), 235-249. doi: 10.4039/n07-058.

Sheffield, C.S., S. Dumesh and M. Cheryomina. 2011. *Hylaeus punctatus* (*Hymenoptera: Colletidae*), a bee species new to Canada, with notes on other non-native species. *JESO* 142: 29-43. http://www.entsocont.ca/uploads/3/0/2/6/30266933/5_jeso_142_sheffield_et_al_29_43.pdf.

Simmons, B.I., A. Balmford, A.J. Bladon, A.P. Christie, A. De Palma, L.V. Dicks, J. Gallego-Zamorano, A. Johnston, P.A. Martin, A. Purvis, R. Rocha, H.S. Wauchope, C.F.R. Wordley, T.A. Worthington and T. Finch. 2019. Worldwide insect declines: An important message, but interpret with caution. *Ecology and Evolution* 9: 3678–3680. https://doi.org/10.1002/ece3.5153.

Sirois-Delisle, C. and J.T. Kerr. 2018. Climate change-driven range losses among bumblebee species are poised to accelerate. *Scientific Reports* 8, 14464. https://doi.org/10.1038/s41598-018-32665-y.

Sivakoff, F.S. and M.M. Gardiner. 2017. Soil lead contamination decreases bee visit duration at sunflowers. *Urban Ecosystems* 20: 1221–1228. https://doi.org/10.1007/s11252-017-0674-1.

Smithsonian Institute. n.d.a. *Bug Info: Butterflies in the United States*. Information Sheet 189. Prepared by the Department of Systematic Biology, Entomology Section, National Museum of Natural History, in cooperation with Public Inquiry Services. Available online: <https://www.si.edu/spotlight/buginfo/butterflyus>.

Smithsonian Institute. n.d.b. *Bug Info: Moths*. Information Sheet 169. Prepared by the Department of Systematic Biology, Entomology Section, National Museum of Natural History, in cooperation with Public Inquiry Services, Smithsonian Institution. Available online: <https://www.si.edu/spotlight/buginfo/moths>.

Spivak, M., E. Mader, M. Vaughn and N.H. Euliss. 2011. The plight of the bees. *Environmental. Science and Technology* 45(1): 34–38. https://doi.org/10.1021/es101468w.

Stanley, D.A., M.P.D. Garratt, J.B. Wickens, J.V. Wickens, S.G. Potts and N.E. Raine. 2015. Neonicotinoid pesticide exposure impairs crop pollination services provided by bumblebees. *Nature* 528: 548–550. https://doi.org/10.1038/nature16167.

Statistics Canada. 2019. Agriculture and Agri-Food Economic Account, 2015. https://www150.statcan.gc.ca/n1/daily-quotidien/190730/dq190730a-eng.htm. Consulted June 29, 2021.

Strange, J.P. 2015. *Bombus huntii*, *Bombus impatiens*, and *Bombus vosnesenskii* (*Hymenoptera: Apidae*) Pollinate Greenhouse-Grown Tomatoes in Western North America. *Journal of Economic Entomology* 108(3): 873–879. https://doi.org/10.1093/jee/tov078.

Straub, L., G.R. Williams, B. Vidondo, K. Khongphinitbunjong, G. Retschnig, A. Schneeberger, P. Chantawannakul, V. Dietemann and P. Neumann. 2019. Neonicotinoids and ectoparasitic mites synergistically impact honeybees. *Scientific Reports* 9: 8159. https://doi.org/10.1038/s41598-019-44207-1.

Stubbs, C.S., F.A. Drummond and S.L. Allard. 1997. Bee conservation and increasing *Osmia* spp. in Maine lowbush blueberry fields. *Northeastern Naturalist* 4(3): 133–144. https://doi.org/10.2307/3858708.

Suckling, D.M., D.E. Conlong, J.E. Carpenter, K.A. Bloem, P. Rendon and M.J.B. Vreysen. 2017. Global range expansion of pest *Lepidoptera* requires socially acceptable solutions. *Biological Invasions* 19: 1107–1119. https://doi.org/10.1007/s10530-016-1325-9.

Tadey, M. 2015. Indirect effects of grazing intensity on pollinators and floral visitation. *Ecological Entomology* 40(4): 451–460. https://doi.org/10.1111/een.12209.

Thogmartin, W.E., R, Wiederholt, K. Oberhauser, R.G. Drum, J.E. Diffendorfer, S. Altizer, O.R. Taylor, J. Pleasants, D. Semmens, B. Semmens, R. Erickson, K. Libby and L. Lopez-Hoffman. 2017. Monarch butterfly population decline in North America: identifying the threatening processes. *Royal Society Open Science* 4:170760. https://doi.org/10.1098/rsos.170760.

Thomas, J.A. 2016. Butterfly communities under threat. *Science* 353(6296): 216–218. DOI: 10.1126/science.aaf8838.

Thomson, D.M. 2016. Local bumble bee decline linked to recovery of honey bees, drought effects on floral resources. *Ecology Letters* 19(10): 1247–1255. https://doi.org/10.1111/ele.12659.

Thuiller, W. 2004. Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology* 10: 2020–2027. https://doi.org/10.1111/j.1365-2486.2004.00859.x.

United Nations Conference on Trade and Development. 2014. *Mexico's agricultural development: perspectives and outlook*. New York and Geneva: United Nations. https://unctad.org/system/files/official-document/ditctncd2012d2_en.pdf.

University of Maryland. 2021. US beekeepers continue to report high colony loss rates, no clear improvement. *ScienceDaily*. www.sciencedaily.com/releases/2021/06/210623193939.htm. Consulted on June 25, 2021.

Upton, J. 2014. Solar farms threaten birds. *Scientific American*. Accessed at: https://www.scientificamerican.com/article/solar-farms-threaten-birds/.

US Department of Agriculture and US Department of Interior. 2015. *Pollinator-friendly Best Management Practices for Federal Lands*. USDA and US Department of Interior. https://www.fs.fed.us/wildflowers/pollinators/BMPs/documents/PollinatorFriendlyBMPsFederalLands05152015.pdf

US Department of Agriculture. 2020. *Pollinator Facts*. Available online: https://www.usda.gov/sites/default/files/documents/pollinator-week-factsheet-06.25.2020.pdf.

US Department of Agriculture. 2021a. ARS Honey Bee Health. https://www.ars.usda.gov/oc/br/ccd/index/. Consulted on June 21, 2021.

US Department of Agriculture. 2021b. Cattle & Beef: Sector at a Glance. https://www.ers.usda.gov/topics/animal-products/cattle-beef/sector-at-a-glance/. Consulted on June 21, 2021.

US Fish and Wildlife Service. 2020. 2020. Monarch (*Danaus plexippus*) Species Status Assessment Report. Available online: https://www.fws.gov/savethemonarch/pdfs/Monarch-SSA-report.pdf

Vadrot, A.B.M., A. Rankovic, R. Lapeyre, P.-M. Aubert, and Y. Laurans Y. 2018. Why are social sciences and humanities needed in the works of IPBES? A systematic review of the literature. *The Innovation: European Journal of Social Science Research* 31: S78–S100. https://doi.org/10.1080/13511610.2018.1443799.

Vanbergen A.J. and the Insects Pollinator Initiative. 2013. Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment* 11(5): 251–259. https://doi.org/10.1890/120126.

van der Sluijs, J.P., N. Simon-Delso, D. Goulson, L. Maxim, J.M. Bonmatin and L.P. Belzunces. 2013. Neonicotinoids, bee disorders and the sustainability of pollinator services. *Current Opinion in Environmental Sustainability* 5(3-4): 293–305. https://doi.org/10.1016/j.cosust.2013.05.007.

van Klink, R., D.E. Bowler, K.B. Gongalsky, A.B. Swengel, A. Gentile and J.M. Chase. 2020. Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. *Science* 368(6849): 417–420. DOI: 10.1126/science.aax9931.

Velthuis, H.H.W. 2002. The historical background of the domestication of the bumble-bee, *Bombus terrestris*, and its introduction in agriculture. In *Pollinating bees: the conservation link between agriculture and nature*. Kevan P, Imperatriz Fonseca VL, eds., 177-184. Brasilia: Ministry of Environment, Brasília.

Villanueva-Gutiérrez, R., D.W. Roubik and W. Colli-Ucán. 2005. Extinction of *Melipona beecheii* and traditional beekeeping in the Yucatán peninsula. *Bee World* 86(2): 35–41. DOI: 10.1080/0005772X.2005.11099651

Villegas, G., A. Bolaños, J. Miranda andA. Zenón. 2000. *Flora nectarífera y polinífera en el estado de Chiapas*. Seceretaria de agricultura, ganaderia y desarrollo rural, Primera Edición, México, Marzo.

Vogel, G. 2017. Where have all the insects gone? *Science* 356(6338): 576–579. DOI: 10.1126/science.356.6338.576.

Wagner, D.L. 2012. Moth decline in the Northeastern United States. *News of The Lepidopterists' Society* 54(2): 52–56. Available online: http://nationalmothweek.org/wp-content/uploads/2012/07/Moth-Decline.pdf.

Wagner, D. L., 2017. Trends in biodiversity: Insects. In *The Encyclopedia of the Anthropocene*, *Vol. 3: Biodiversity*, D. A. Dellasala and M. I. Goldstein, ed., 131–143. Amsterdam: Elsevier.

Wagner, D.L. 2020. Insect declines in the Anthropocene. *Annual Review of Entomology* 65: 457–80. https://doi.org/10.1146/annurev-ento-011019-025151.

Wagner, D.L., E.M. Grames, M.L. Forister, M.R. Berenbaum and D. Stopak. 2021. Insect decline in the Anthropocene: Death by a thousand cuts. *Proceedings of the National Academy of Sciences* 118(2). DOI: 10.1073/pnas.2023989118

Walker, L. and S. Wu. 2017. Pollinators and pesticides. In *International Farm Animal, Wildlife and Food Safety Law*. G. Steier and K. K. Patel, ed., 495–513.Switzerland: Springer International Publishing.

Walther, G-R., A. Roques, P.E. Hulme, M.T. Sykes, P. Pyšek, I. Kűhn, M. Zobel, S. Bacher, Z. Botta-Dukát, H. Bugmann, B. Czúcz, J. Dauber, T. Hickler, V. Jarošik, M. Kenis, S. Klotz, D. Minchin, M. Moora, W. Nentwig, J. Ott, V.E. Panov, B. Reineking, C. Robinet, V. Semenchenko, W. Solarz, W. Thuiller, M. Vilà, K. Vohland and J. Settele. 2009. Alien species in a warmer world: risks and opportunities. *Trends in Ecology and Evolution* 24(12): 686–693. https://doi.org/10.1016/j.tree.2009.06.008.

Weiss, S.B. 1999. Cars, cows, and checkerspot butterflies: nitrogen deposition and management of nutrient-poor grasslands for a threatened species. *Conservation Biology* 13(6): 1476–1486. https://doi.org/10.1046/j.1523-1739.1999.98468.x.

Wepprich, T., J.R. Adrion, L. Ries, J. Wiedmann and N.M. Haddad. 2019. Butterfly abundance declines over 20 years of systematic monitoring in Ohio, USA. *PLoS ONE* 14(7): e0216270. https://doi.org/10.1371/journal.pone.0216270.

Wethington, S.M. and N. Finley. 2008. Addressing hummingbird conservation needs: an initial assessment. Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics. Available online: https://www.partnersinflight.org/wp-content/uploads/2017/03/Wethington-S.-M.-and-N.-Finley-p-662-666.pdf.

Winfree, R., B.J. Gross and C. Kremen. 2011. Valuing pollination services to agriculture. *Ecological Economics* 71: 80–88. https://doi.org/10.1016/j.ecolecon.2011.08.001.

Winsa, M., E. Öckinger, R. Bommarco, R. Lindborg, S.P.M. Roberts, J. Wärnsberg and I. Bartomeus. 2017. Sustained functional composition of pollinators in restored pastures despite slow functional restoration of plants. *Ecology and Evolution* 7(11): 3836–3846. https://doi.org/10.1002/ece3.2924.

Winter, K., L. Adams, R. Thorp, D. Inouye, L. Day, J. Ascher and S. Buchmann. 2006. Importation of non-native bumble bees into North America: potential consequences of using *Bombus terrestris* and other non-native bumble bees for greenhouse crop pollination in Canada, Mexico, and the United States. San Francisco: North American Pollinator Protection Campaign. White Paper.

Wojcik, V.A. and S. Buchmann. 2012. Pollinator conservation and management on electrical transmission and roadside rights-of-way: A review. *Journal of Pollination Ecology* 7(3): 16–26. http://dx.doi.org/10.26786/1920-7603%282012%295.

Woodcock, B.A J.M. Bullock, R.F. Shore, M.S. Heard, M.G. Pereira, J. Redhead, L. Ridding, H. Dean, D. Sleep, P. Henrys, J. Peyton, S. Hulmes, L. Hulmes, M. Sárospataki, C. Saure, M. Edwards, E. Genersch, S. Knäbe and R.F. Pywell. 2017. Country-specific effects of neonicotinoid pesticides on honey bees and wild bees. *Science* 356(6345): 1393–1395. DOI: 10.1126/science.aaa1190.

Wyllie de Echeverria, V.R. and T.F. Thornton. 2019. Using traditional ecological knowledge to understand and adapt to climate and biodiversity change on the Pacific coast of North America. *Ambio* 48: 1447–1469. https://doi.org/10.1007/s13280-019-01218-6.

Yesson, C., P. W. Brewer, T. Sutton, N. Caithness, J. S. Pahwa, M. Burgess, W. A. Gray, R. J. White, A. C. Jones, F. A. Bisby, and A. Culham. 2007. How global is the global biodiversity information facility? *PLoS ONE* 2(11): e1124. https://doi.org/10.1371/journal.pone.0001124.

Young, B.E., S. Auer, M. Ormes, G. Rapacciuolo, D. Schweitzer and N. Sears. 2017. Are pollinating hawk moths declining in the Northeastern United States? An analysis of collection records. *PLoS ONE* 12(10): e0185683. *https://doi.org/10.1371/journal.pone.0185683*.