Food and Agriculture Organization of the United Nations

COMMISSION ON GENETIC RESOURCES FOR FOOD AND AGRICULTURE

# SUSTAINABLE USE AND CONSERVATION OF INVERTEBRATE POLLINATORS

BACKGROUND STUDY PAPER NO. 72

# SUSTAINABLE USE AND CONSERVATION OF INVERTEBRATE POLLINATORS

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**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS**
**ROME, 2023**

Required citation:
Aizen, M.A., Basu, P. , Bienefeld, K., Biesmeijer, J.C., Garibaldi, L.A., Gemmill-Herren, B, Imperatriz-Fonseca, V.L., Klein, A-M., Potts, S.G., Seymour C.L. & Vanbergen, A.J. 2023. *Sustainable use and conservation of invertebrate pollinators*. Background Study Paper, No. 72. Commission on Genetic Resources for Food and Agriculture. Rome, FAO. https://doi.org/10.4060/cc6499en



ISBN 978-92-5-137943-1

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# Acknowledgements

This background study paper has been prepared at the request of the Secretariat of the Commission on Genetic Resources for Food and Agriculture (the Commission), with a view to facilitate consideration by the Commission of the sustainable use and conservation of invertebrate pollinators, at its Eighteenth Regular Session. It was prepared under the coordination of Hien Ngo, from the Commission Secretariat.

The lead authors would like to express special thanks to all the contributing authors: Shamsul Bahri Bin Abd Razak (Department of Agrotechnology, Universiti Malaysia Terengganu, Terengganu Darul Iman, Malaysia); Abu Hassan Abdul Jalil (International Meliponine Friendship Federation, Selangor, Malaysia); Denise Araujo Alves (Department of Entomology and Acarology, University of São Paulo, Piracicaba, Brazil); Tom D. Breeze (Centre for Agri-Environmental Research, School of Agriculture, Policy and Development, Reading University, Reading, United Kingdom of Great Britain and Northern Ireland); Luciano Costa (Vale Institute of Technology Sustainable Development, Belém, Brazil); Tiago Mauricio Francoy (School of Arts, Sciences and Humanities, University of São Paulo, São Paulo, Brazil); Tim A. Heard (Sugarbag Bees, Brisbane, Australia); Cristiano Menezes (Brazilian Agricultural Research Corporation, EMBRAPA Environment, São Paulo, Brazil); Guiomar Nates-Parra (Departamento de Biología, Facultad de Ciencias, Universidad Nacional de Colombia, Bogotá D.C., Colombia); Kiatoko Nkoba (International Centre of Insect Physiology and Ecology, Nairobi, Kenya); Alain Pauly (Royal Belgian Institute of Natural Sciences, Brussels, Belgium); Willem Proesmans (Agroécologie, Institut national de la recherche agronomique, Dijon, France); José Javier G. Quezada-Euán (Department of Apiculture, Autonomous University of Yucatan, Mérida, Mexico); David W. Roubik (Smithsonian Tropical Research Institute, , Balboa Ancón, Panama); Josef Settele (UFZ Helmholtz Centre for Environmental Research, Halle [Saale], Germany and iDiv, German Centre for Integrative Biodiversity Research, Leipzig, Germany); and Ayrton Vollet-Neto (The Amazon Conservation Team, Zorg en Hoop, Suriname).

Thanks go to the Commission's National Focal Points for participating in a survey on pollinator-related activity and to the Commission and its Members for providing comments on the draft study that was presented to the Commission's Eighteenth Regular Session.

Thanks also go to Promote Pollinators, Apimondia, the United Nations Development Programme (UNDP)'s Biodiversity and Ecosystem Services Network (BES-Net) programme, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Convention on Biological Diversity (CBD) for supporting the dissemination and publicizing of survey.

# Abbreviations and acroynms

| | |
|---|---|
| ALARM | Assessing Large-scale Environmental Risks with Tested Methods |
| BAMBU | business-as-might-be-usual |
| CBD | Convention on Biological Diversity |
| CCD | colony collapse disorder |
| DAD-IS | Domestic Animal Diversity Information System |
| DWV | deformed wing virus |
| EFSA | European Food Safety Authority |
| EPI | European Pollinator Initiative |
| EUPoMS | European Pollinator Monitoring Scheme |
| FAO | Food and Agriculture Organization of the United Nations |
| GBIF | Global Biodiversity Information Facility |
| GIAHS | Globally Important Agricultural Heritage Systems |
| GMO | genetically modified organism |
| IPBES | Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services |
| IPI | International Pollinator Initiative |
| IPM | integrated pest management |
| IUCN | International Union for the Conservation of Nature |
| NBSAP | National biodiversity strategy and action plan |
| STEP | Status and Trends of European Pollinators |
| WOAH | World Organisation for Animal Health |

# Executive summary

## Status and trends of invertebrate pollinators, including honey bees

Almost 90 percent of flowering plant species depend, to varying degrees, on pollinators (both vertebrate and invertebrate) and the pollination services they provide. Approximately three-quarters of the world's crops producing fruits and seeds for human consumption depend, at least in part, on pollinators for sustained production, yield and quality. Animal-pollinated crops are rich in micronutrients, and there is growing evidence of a direct link between pollinator-dependent crops and nutritionally adequate diets, especially in the developing world. These crops contain, in some cases, significant levels of the lipids, vitamin A and related carotenoids, vitamins C and E, lycopene, the antioxidants β-cryptoxanthin and β-tocopherol, calcium, fluoride, folate (iron), etc. needed for healthy human diets.

Worldwide, agriculture is now almost twice as dependent on pollinators as it was 60 years ago. The agricultural area represented by pollinator-dependent crops was 19.4 percent in 1961 but had increased to 32.8 percent by 2016. In other words, the pollinator dependence of global agriculture – measured in terms of the proportion of area cultivated with pollinator-dependent crops – increased by about 70 percent between 1961 and 2016.

Approximately 10 percent of crop production is dependent on pollination services. This is calculated to have a global annual market value of up to USD 577 billion. Without pollinators, many plant species would decline and eventually disappear. This would threaten nature, human well-being and the economy. Without animal pollination, changes in global crop supplies could result in higher prices for consumers and reduced profits for producers. The relative economic impacts of such pollinator losses could be highest in several regions of Africa. Almond growers in California (United States of America) produce 80 percent of global almond production, utilizing over 1 million managed honey-bee hives to maintain a USD 6 billion industry. In the United States of America, the value of wild pollinators for a mere seven crops has been estimated at over USD 1.5 billion annually. A study of the value of native bumble-bee pollination in apple production in Argentina found that, where bumble bees were excluded, fruit set and the number of fruits decreased by almost a half and that farmers saw a 2.4-fold decrease in earnings. However, the monetary value of pollination and pollinator natural capital is difficult to estimate precisely, and there is a lack of economic evidence for the non-monetary values of pollination services, which makes accounting in a single form difficult.

### *Status and trends of pollinators*

Several recent global studies confirm that wild pollinators are declining. These findings support those of earlier studies that showed that wild-bee populations were declining in occurrence and diversity (and abundance for certain species) at local and regional scales, with the evidence for this coming primarily from northwest Europe and North America. The earlier studies reported that data limitations in some regions (Asia, Africa, Latin America and the Caribbean, the Near East and the Pacific) precluded general statements on the status of wild bees in these regions or globally. A study published in 2021, based on Global Biodiversity Information Facility (GBIF) records of wild bees, reveals that about 25 percent fewer species were reported between 2006 and 2015 than in the period before the 1990s. The authors conclude that there have been declines in the species richness of bees in all continents except Oceania and that this appears to be a relatively recent trend that accelerated in the 1990s.

A second new study mapped global bee species richness by accounting for bee checklists, verified observations and published records. The largest hotspot areas for bee species richness were reported to be in the southwestern United States of America, the Mediterranean Basin into the Near East, and Australia.

Nearly one-quarter of bumble-bee species assessed using the International Union for Conservation of Nature (IUCN) Red List criteria are categorized as Threatened. The proportion of threatened bumble bees varies by region: 21.0 percent in Europe; 26.0 percent in North America; 45.5 percent in Mesoamerica; and 12.5 percent in South America. Assessments for Asia, the most bumble-bee species-rich region, are pending. Although efforts to document the status of bumble bees have increased, there are still many regions that have not been assessed and/or are Data-Deficient.

Managed honey-bee colonies unequivocally contribute significantly to agricultural productivity by providing pollination services. Globally, the number of managed honey-bee hives has increased by about 80 percent over the last 60 years. However, trends and data availability vary greatly from region to region. For example, in Africa there was a continuous increase in the number of hives (about 150 percent in total) over the period between 1961 and 2019, while the increase in Asia over the same period was 300 percent. Continued research and development on honey bees is valuable. Still largely unquantified is the relatively recent global phenomenon of rapidly increasing urban beekeeping, an activity presumed to have sizable sociological and ecological consequences.

Stingless bees also make a substantial contribution to ecosystem functioning and pollination services in some regions and countries, and for certain crops. Like honey bees, stingless bees are eusocial and therefore make frequent flower visits, and could contribute significantly to pollination services, including the pollination of crops. A recent census of stingless bees in three regions of the world highlighted the domestication potential of 560 species (431 in the Neotropical region, 91 in the Indo-Malayan/Australasian region and 38 in the Afrotropical region). However, stingless bees and their links to crop pollination remain understudied in these regions.

There have been few studies of the status of subspecies (geographic races) of invertebrate pollinators. The subspecies-level information reported here is focused on honey-bee subspecies and honey-bee genetic resources, some of which are under threat. Native or indigenous honey-bee subspecies have adapted through evolution to local environmental conditions (as with most local breeds of animals). They have greater resilience and resistance to threats and provide critical reservoirs of genetic resources and diversity.

Based on morphology, phenotypes, behaviour and genetics, five distinct honey-bee evolutionary lineages and 29 distinct subspecies, can be distinguished: 1) A-lineage – Africa; 2) M- lineage – western and northern Europe and central Asia; 3) C-lineage – central and southern Europe; 4) O-lineage – Caucasus, Türkiye, Near East, Cyprus, Crete and western Asia; and 5) Y- lineage – Arabian Peninsula and Ethiopian highlands.

A variety of *in situ* and *ex situ* conservation strategies can be used to safeguard honey-bee subspecies and genetic diversity and meet the demands of beekeepers, including genetic assessment of populations, gamete cryopreservation, effective breeding strategies for genetic improvement of local subspecies (e.g. selection programmes and artificial insemination programmes) and establishment of a common repository for characterization data. To date, there are only a few honey-bee conservation programmes, the majority of which are concentrated in Europe – which may be a result of the region's high honey-bee subspecies diversity being endemic to Europe. There is a need for stronger networking and collaboration among institutions and researchers, and for common approaches to collecting, cataloguing, storing and using genetic material. A few initiatives are currently being set up, such as a working group on honey-bee gene banking led by the International Federation of Beekeepers' Associations (Apimondia). However, such efforts need to be increased and better coordinated for more effective conservation.

### *Causes of pollinator decline*

The importance of drivers and the risks they pose to pollinators (i.e. loss) differs from region to region. New evidence shows the most important direct drivers across all regions are land-use change (land cover and configuration), intensive agricultural management and pesticide use. Additional drivers of pollinator loss include environmental pollution, invasive alien species, including introduced bees, pathogens and climate change. Climate change is likely to increase in importance as a major driver, likely exacerbating the risks from other drivers.

Different regions of the world have experienced different rates of agricultural intensification. In the last 25 years, more areas have been brought under cultivation in developing regions, and agricultural expansion, conventional intensification and urbanization are ongoing trends in regions of the Global South, driven in part by international trade. Various factors associated with agricultural intensification affect pollinator health and plant–pollinator interaction, either directly or synergistically.

In 2016, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) reported that pesticides, particularly insecticides, have a broad range of lethal and sublethal effects on pollinators under controlled experimental conditions and highlighted that, at the time, few results were available from field-level studies assessing the effects of pesticides and their combinations on bees (other than honey bees) at field-realistic doses. Since then, studies conducted in Europe and North America on the effects that actual field exposure to pesticides have on wild bees have found adverse, including sublethal, impacts: for example, reductions in numbers of nests and offspring among ground-nesting bees and reductions in bee density, colony growth and reproduction among bumble bees and other solitary bees nesting above ground. There is still a lack of evidence available from other regions.

Trends in total pesticide use (including insecticides, herbicides and fungicides) for the period since 1995 differ across the regions of the world. There were substantial increases in total pesticide use in parts of North and South America and Asia. It is important to note that the use patterns of specific pesticide groups in different regions have not remained uniform during this period. For example, herbicide use has increased substantially in many parts of the world, particularly in North and South America and Africa. In the case of insecticides, use per unit area has grown substantially in certain regions of the world, for example in Oceania, and marginally in Africa. In South America, Southern Asia and Central Asia, there are decreasing trends in insecticide use per unit area. However, it should be noted that the assessment of pesticides on the environment should not just consider exposure rates but also other aspects such as modes of exposure and the dangers and potential impacts of combinations of pesticides (e.g. synergistic effects), etc.

### *Sustainable management practices and conservation measures*

There are three types of honey-bee breeding programmes – commercial, conservation and research. Breeding programmes provide the opportunity to conserve genetically attractive local subspecies. Such programmes are important for many European native subspecies, which may be hybridized or replaced by, for example, *Apis mellifera carnica* or *Apis mellifera ligustica. Apis cerana* is facing similar threats of replacement and hybridization in Asia. Honey-bee genetic resources can be used for breeding and require conservation as they are classed as animal genetic resources for food and agriculture, and as such data on them are recorded in the Domestic Animal Diversity Information System (DAD-IS).

Pollinator-friendly management systems, practices and processes have the potential to maintain rich and abundant wild-pollinator communities if sustained over time. These include sustainable intensification, agroecology, organic farming and integrated pest management (IPM). The findings of recent studies support the view that focusing on ecological intensification can help reduce threats to pollinators while maintaining and providing other benefits such as natural biocontrol, better soil function and sustained food security. An approach of this kind involves aiming to increase long-term crop productivity by enhancing beneficial biodiversity, including pollinator diversity – and associated ecosystem functions and services/nature's contributions to people – while minimizing the use of synthetic inputs and the expansion of croplands.

Many broader conservation efforts, for example maintaining habitat diversity or increasing habitat richness, benefit a wide range of organisms, including invertebrate pollinators and plants, but co-benefits of this kind have not been well researched. In the case of increased habitat complexity, Shackelford *et al.* (2013) found that this landscape complexity had positive effects on both pollinators and natural enemies (pest control), resulting in less vulnerability of the ecosystem services they provide. There has also been little research on whether targeted conservation actions for pollinator habitat enhance overall biodiversity and other ecosystem services.

### *Policy and regulations*

While an increasing number of countries have adopted national pollination strategies, pollinator-related issues are rarely addressed by a single dedicated law or regulation. They are instead usually integrated or mainstreamed into – or covered by – national laws of various kinds, such as those addressing the conservation of endangered species, the authorization and use of pesticides, trade in bee products (honey, etc.) or livestock breeding. Administrative responsibility for such laws often lies with different government agencies at national and regional levels. This often makes it difficult to develop and implement coordinated management strategies for pollinators. In addition, the lack of training and building capacity of technicians and land managers on pollinator-related approaches makes implementation difficult. National laws specifically addressing pollinators usually focus on honey bees in the context of beekeeping (trade, biosecurity, pests/diseases).

The situation at international level is similar to that at national level. Responsibility for pollinator-related issues lies with different bodies and instruments, and there is no single dedicated body at global level overseeing the status of pollinators and coordinating action on the use and conservation of pollinators across relevant fora and instruments. The International Pollinator Initiative has led to significant progress, and this is reflected in many national and subnational initiatives, projects and even laws addressing pollinators. To date, however, there is no dedicated body that systematically reviews the status of pollinators at regular intervals, coordinates exchange of pollinator-related knowledge and experiences or aims to ensure coherent action on pollinators at global level.

National biodiversity strategies and action plans (NBSAPs) are policy instruments that frame the aims and objectives of the Convention on Biological Diversity (CBD) in national contexts and guide national actions. A qualitative analysis of the NBSAPs in a 173-country database (covering all NBSAPs available on the CBD website) found that the NBSAPs from 117 countries had an average of only 0.0142 percent inclusion of the words "bee/s", "beekeeping", "pollinators" or "pollination". This indicates relatively little recognition of the significance pollinators and pollination play in achieving many conservation objectives, but at the same time highlights the opportunities that exist to increase awareness among decision-makers.

### Global and regional pollinator initiatives

At its 14th meeting, the Conference of the Parties to the CBD adopted the Plan of Action 2018–2030 for the International Pollinator Initiative and emphasized that the purpose of the Plan of Action was to "help Parties, other Governments, indigenous peoples and local communities, relevant organizations and initiatives to implement decision XIII/15".[1] The purpose of the International Pollinator Initiative is to support help countries and stakeholders implement the following four overall objectives:

(a) In implementing coherent and comprehensive policies for the conservation and sustainable use of pollinators at the local, subnational, national, regional and global levels, and promoting their integration into sectoral and cross-sectoral plans, programmes and strategies;

(b) In reinforcing and implementing management practices that maintain healthy pollinator communities, and enable farmers, beekeepers, foresters, land managers and urban communities to harness the benefits of pollination for their productivity and livelihoods;

(c) In promoting education and awareness in the public and private sectors of the multiple values of pollinators and their habitats, in improving the tools for decision-making, and in providing practical actions to reduce and prevent pollinator decline;

(d) In monitoring and assessing the status and trends of pollinators, pollination and their habitats in all regions and to address gaps in knowledge, including by fostering relevant research.

Within the same decision it was noted that FAO would facilitate the implementation of the International Pollinator Initiative through guidance and technical advice to countries and support decision-making processes on pollination, including on the use of chemicals in agriculture, protection programmes for native pollinators in natural ecosystems, promotion of biodiverse production systems, crop rotation, monitoring of native pollinators and environmental education.

Since the establishment of the International Pollinator Initiative, four regional initiatives (the African Pollinator Initiative, the European Pollinator Initiative, the North American Pollinator Protection Campaign and the Oceania Pollinator Initiative) have been established. A fifth, the Asian Pollinator Initiative, is in its early stages of development. Approximately 30 national initiatives have also been, or are in the process of being, established. These initiatives, however, are not being developed equally across regions and vary in their scope and ambition: in North America, both Canada and the United States of America have national initiatives; Europe and Central Asia has 15 national initiatives (representing 31 percent of the countries in the region); Latin America and the Caribbean has six national pollinator strategies (representing 18 percent of the countries in the region); Asia has four national pollinator initiatives (representing 16 percent of the countries in the region); and Africa has three national pollinator strategies (representing 6 percent of the countries in the region). The Near East and North Africa has only one national initiative (representing 4.8 percent of the countries in the region). There are no national pollinator strategies in the Southwest Pacific region, and the sole national pollinator strategy in the Near East and North Africa region is in the very early stages of development. Lastly, as part of the work completed under the International Pollinator Initiative, an Indigenous Peoples' Pollinators Initiative has been launched. In addition, FAO, in partnership with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), is preparing a regional grant application to the

[1] https://sdgs.un.org/un-system-sdg-implementation/secretariat-convention-biological-diversity-cbd-34573

International Climate Initiative financing body under the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) for a project on knowledge gaps on pollinators and pollination services in the Latin American and the Caribbean region.

## Gaps and needs

Many scientific and technical gaps still exist with respect to invertebrate pollinators and their management. Basic information on invertebrate pollinator diversity, abundance, richness and occurrence is lacking because of taxonomic challenges and the absence of standardized monitoring protocols. Efforts to address both these issues could be complemented and supported by citizen scientists. In 2022, the European Commission's Joint Research Centre developed a proposal for a European Union Pollinator Monitoring Scheme within the European Union's Biodiversity Strategy. The proposed scheme would provide a standardized, cost-effective, pragmatic approach to monitoring several invertebrate pollinator taxa simultaneously. Implementing this standardized approach in other regions that lack baseline data on pollinators would enable direct comparisons of pollinator data and could help inform decision-makers.

Despite the tremendous efforts made by the research community in recent decades, there are still significant gaps in research on, and knowledge of, invertebrate pollinators and pollination services. These knowledge gaps are not equally distributed across regions. For example, data on bee distribution are highly heterogeneous, with records largely missing for most of Asia, Africa, the Near East and parts of South America, although data on abundance and population trends are generally lacking globally. Where drivers of change are concerned, understanding of the proximate causes of pollinator decline associated with habitat loss and fragmentation is limited, despite land-use change having been identified as the largest risk to pollinators. For example, in Africa, the impact of land-use change (cover and configuration) on pollinators and their subsequent impacts on people and their well-being are still largely unknown. We do not yet have good knowledge of the impact of single drivers on pollinators and pollination services, l*et al*one the impact of multiple drivers (e.g. compounding impacts of climate change and other drivers). Another knowledge gap relates to the pollination dependency of most crop varieties, although we know that almost all crops have a mixed mating system. Without this critical information, our estimates of the importance of pollinators remain vague. Lastly, knowledge of, and research on, the impact of management practices on all invertebrate pollinators and pollination services are also lacking, including in the following areas: meta-analyses of the effects of organic farming on pollinators, pollination and crop yield; the effect of reducing pesticides (e.g. as part of an ecological-intensification approach) on both crop productivity and pollinator populations – we have no information on how organic pesticides affect pollinators and how this differs from the effects of chemical pesticides; changes to the resilience of pollinator populations and communities and pollinator-food webs following the application of ecological intensification interventions; and the direct and indirect effects of honey bees and other managed bees (including stingless bees) on wild plants and wild pollinators via competition and pathogen spillover.

# Introduction

FAO uses the definition of pollination from *The forgotten pollinators* (Buchmann and Nabhan, 1997) "the process of moving pollen from the anthers of one flower to the stigma of another or the same flower. Equally vital processes of fertilization and seed set follow from pollination. Pollination can be affected either by abiotic means such as gravity, wind and water or by animals such as bats and bees."[1] Pollination is recognized as a critical regulating service (a benefit "obtained from the regulation of ecosystem processes"), both under the ecosystem services framework of the Millennium Ecosystem Assessment (2005) and the more recent *Assessing nature's contributions to people framework* (i.e. pollination and dispersal of seeds and other propagules) (Díaz *et al.*, 2018).

Almost 90 percent of wild-growing plant species depend, to various degrees, on pollinators (both vertebrate and invertebrate) and the pollination services they provide (Ollerton *et al.*, 2011). Approximately three-quarters of the world's crops that produce fruits and seeds for human consumption depend, at least in part, on pollinators for sustained production, yield and quality (Klein *et al.*, 2007). Animal-pollinated crops are rich in micronutrients, and there is growing evidence of a direct link between pollinators and pollinator-dependent crops and nutritionally adequate diets, especially in the developing world. These crops contain, in some cases, significant levels of the lipids, vitamin A and related carotenoids, vitamins C and E, lycopene, antioxidants β-cryptoxanthin and β-tocopherol, calcium, fluoride, folate (iron), etc. needed for healthy human diets (Eilers *et al.*, 2014; Ellis *et al.*, 2015; Smith *et al.*, 2015; Klein *et al.*, 2018).

A majority of the dominant animal pollinators of both crops and wild plants are invertebrates (or more specifically insects). The most important group are bees, but other insects such as flies, butterflies, moths, wasps, beetles and thrips are also valuable pollinators (Klein *et al.* 2007; Potts *et al.*, 2016).

Worldwide, agriculture is now almost twice as dependent on pollinators as it was 60 years ago. The agricultural area represented by pollinator-dependent crops was 19.4 percent in 1961 but had increased to 32.8 percent by 2016. In other words, the pollinator-dependence of global agriculture – measured in terms of the proportion of area cultivated with pollinator-dependent crops – increased by ~70 percent between 1961 and 2016 (update of analysis presented in Aizen *et al.*, 2009). Approximately 10 percent of crop production is dependent on pollination services; this is calculated to have an annual global market value of up to USD 1 trillion/year (figure refers to value of pollination services in the short term, which is defined as one year/cropping season following a pollinator collapse) (Lippert *et al.*, 2021). Depending on the overall price elasticity assumed, the short-term effects of a total pollinator loss lie between 1 and 2 percent of global gross domestic product (GDP) (Lippert *et al.*, 2021). Without pollinators, many plant species would decline and eventually disappear – this would threaten nature, human well-being and the economy. Without animal pollination, changes in global crop supplies could result both in increased prices to consumers and in reduced profits to producers; the relative economic impacts of pollinator losses could be highest in several regions of Africa (Bauer and Wing, 2016).

Around EUR 16.8 billion/year (corrected for 2021) of the European Union's annual agricultural output is directly dependent on insect pollinators (Leonhardt *et al.*, 2013; European Commission Joint Research Centre, 2021). In Germany, crop pollination services are valued at EUR 3.8 billion (Lippert *et al.* 2021). In California (United States of America), almond growers produce 80 percent of global almond production, utilizing over 1 million managed honey-bee hives to maintain a USD 6 billion industry (USDA, 2020). In the United States of America generally, the value of wild pollinators for a mere seven crops has been estimated to be more than USD 1.5 billion annually. In Argentina, a valuation study of native bumble-bee pollination in apple production was evaluated; where bumble bees were excluded, fruit set and the number of fruits decreased by almost a half and farmers saw a 2.4-fold decrease in earnings (Pérez-Méndez *et al.*, 2020).

The full value of pollination services to food systems is difficult to estimate because of, inter alia, a lack of information on the benefits of pollination throughout the supply chain (e.g. to food processors or end consumers). We also lack any estimates of the stocks

[1] http://www.fao.org/pollination/resources/glossary/en/

or values of pollinator natural capital. Furthermore, estimating the value of pollination services in purely monetary terms is complicated by a lack of economic value estimates for many non-monetary benefits (but see for example Breeze *et al.* 2015), many of which are not compatible with monetary exchange. A more holistic, multicriteria approach to valuation that goes beyond monetary values alone could give a more complete picture of the benefits that pollinators provide (Senapathi *et al.*, 2015).

Recognizing the importance of invertebrate pollinators, the Commission on Genetic Resources for Food and Agriculture (Commission) at its Seventeenth Regular Session, in 2019, adopted its Work Plan for the Sustainable Use and Conservation of Micro-organism and Invertebrate Genetic Resources for Food and Agriculture and decided to address pollinators, including honey bees, at its Nineteenth Regular Session (FAO, 2019). Building on global assessments addressing pollinators published in 2016 and 2019, respectively, by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and FAO (IPBES, 2016; FAO, 2019), this study provides up-to-date information on the status and trends of invertebrate pollinators, maps relevant regional and international initiatives, and identifies gaps and needs.

# Chapter 1. Status and trends of invertebrate pollinators

There is growing evidence of wild pollinator population declines and deficits in crop production due to insufficient pollination, while global demand for pollination services is at an all-time high. Conversely, managed honey-bee populations, while declining in North America and parts of Europe, are increasing in many countries. Observed trends in wild pollinator populations have mostly linked them to changes in land management, climate change and agrochemical use, although these analyses are largely restricted to Europe and North America. Restoring or diversifying habitats and reducing management pressures, such as pesticides and landscape simplification, have been shown to positively affect wild pollinator populations and the health of managed honey bees (Kovács-Hostyánszki *et al.*, 2017; Tamburini *et al.*, 2020).

In response to evidence of declines in pollinators and pollination, public and policy attention globally and substantial efforts are underway to respond, through national pollinator strategies and action plans. The first outcome of the IPBES was a global assessment of pollinators, pollination and food production (IPBES, 2016); this underpinned the adoption of new commitments to support pollinator conservation by the Parties to the Convention on Biological Diversity (CBD) and the signatories to the Coalition of the Willing on Pollinators (Promote Pollinators) and subsequent steps towards the development of national pollinator strategies and national biodiversity strategy and action plans (NBSAPs). One clear message from the IPBES pollination assessment was that evidence on the status and trends of pollinator populations, threats to pollinators and the impacts of pollinator decline is concentrated in high-income countries, rather than in the regions thought to be most vulnerable to declines in pollinator diversity and pollination services (Millard *et al.*, 2020; Dicks *et al.*, 2021).

## 1.1 Species-level patterns

### 1.1.1. Status and trends of wild bees

#### Global

*Wild bees*

Bees are the most important group of pollinators (Free, 1993; Nabhan and Buchmann, 1997; Klein *et al.*, 2007; Potts *et al.*, 2010). There are more than 20 000 described species (Michener, 2007). Both wild and managed bees deliver important pollination services to crops and wild plants in addition to a myriad of other benefits to human well-being (Winfree *et al.*, 2007; Ollerton *et al.*, 2011; Klein *et al.*, 2018; Senapathi *et al.*, 2021). In an important meta-analysis, Garibaldi *et al.* (2013) found that wild insects pollinate crops more effectively than honey bees and that visits from wild insects doubled rates of fruit set.

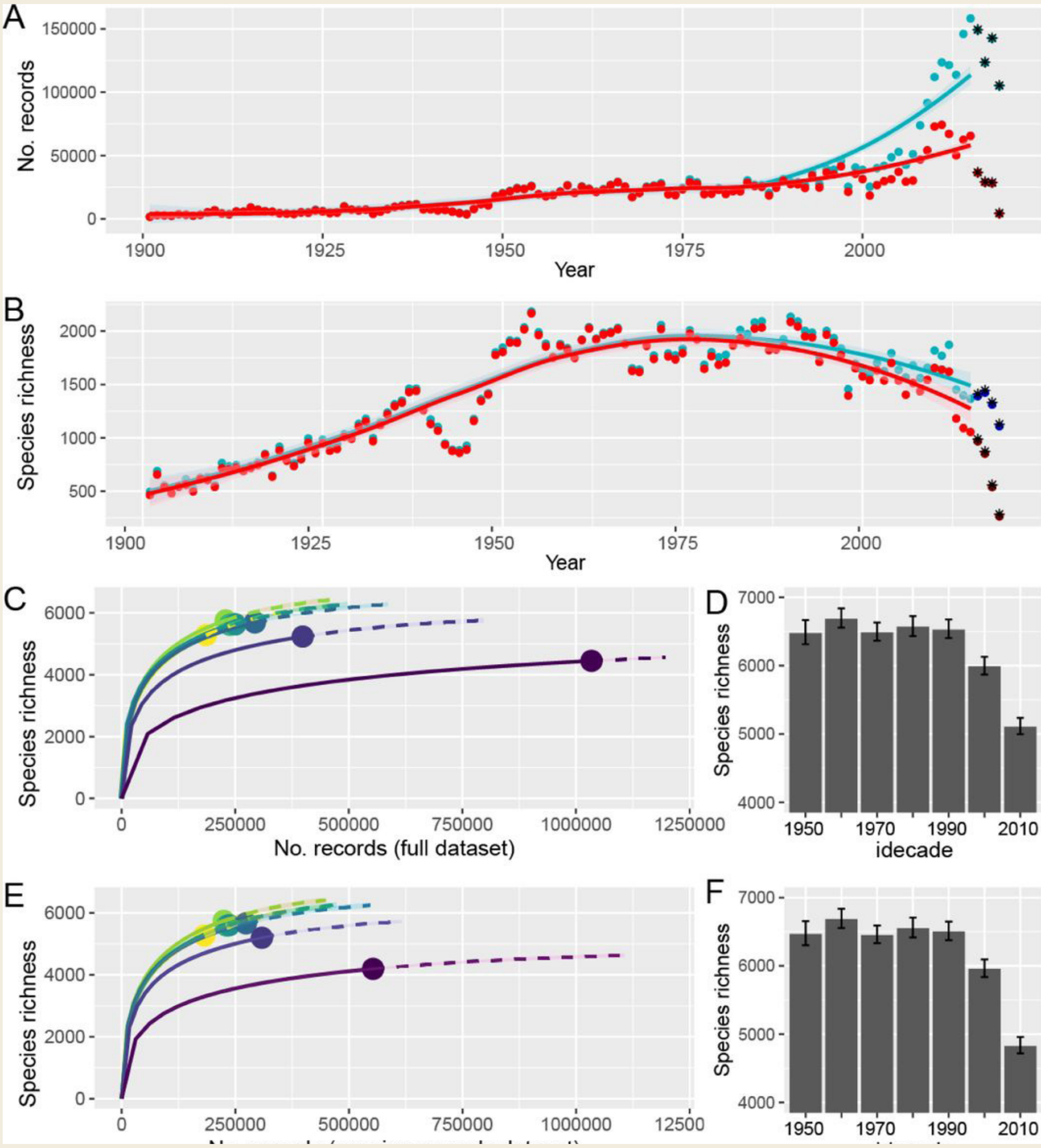
The main conclusions on wild bees from the IPBES (2016) pollinator assessment were that: (i) there had been declines in occurrence and diversity at local and regional scales in northwest Europe and North America; (ii) a lack of data for Asia, Africa, Latin America and the Caribbean, the Near East and the Pacific precluded any general statement on their regional status, despite some records of local declines; and (iii) abundance data were missing for nearly all species in all regions.

Two recent studies have substantially extended our knowledge of the status and trends of wild bees. Orr *et al.* (2021) analysed more than 5.8 million bee-occurrence records to describe global patterns of bee distribution and species richness. They found that bees exhibit a rare bimodal pattern of species richness, with higher species richness at mid-latitudes and peaks in xeric and some temperate areas. Major hotspots of richness were found in southwestern areas of the United States of America, southern and western coastal South America, the Mediterranean Basin, the Near East, Australia and South Africa (Orr *et al.*, 2021).[2]

Zattara and Aizen (2021) used more than 3.4 million Global Biodiversity Information Facility (GBIF) occurrence records – covering more than a century of specimen collection – to assess trends in global bee species richness and found approximately 25 percent fewer species reported between 2006 and 2015 than in the period before the 1990s (Figure 1). They concluded that there had been declines in the species richness of bee records in all continents except Oceania, and that this appears to be a relatively recent trend that accelerated in the 1990s. In parallel with the declines in species richness was a shift to increasing dominance of the records by a few species, such as invasive *Bombus terrestris* in southern South America and the western

[2] Please see Figure 4 in Orr, M.C. *et al.*, 2021 for more details.

**Figure 1. Trends in global bee species richness using Global Biodiversity Information Facility occurrence records**




*Notes*: A: Number of worldwide GBIF records of Anthophila (bees) occurrences per year in the full (cyan) and specimen-only (red) datasets. The curves represent loess fits with a smoothing parameter of a = 0.75 up to 2015. The four most recent years (2016–2019, labelled with an asterisk) were excluded from further analysis. B: Number of bee species found each year in the full (cyan) and specimen-only (red) datasets. C: Chao's interpolation/extrapolation (iNEXT) curves based on the full dataset. Data were binned into ten-year periods (idecades) from 1946 to 2015. The circles show actual number of specimen records and separate interpolated (left, full line) from extrapolated (right, dashed line) regions of each curve. D: Values of the asymptotic richness estimator by idecade (see main text) for the full dataset (error bars mark upper- and lower-95 percent confidence intervals). E: Chao's iNEXT curves based on the specimen-only dataset. F: Values of the asymptotic richness estimator by idecade for the specimen-only dataset.

*Source*: Zattara, E.E. & Aizen, M.A. 2021. Worldwide occurrence records suggest a global decline in bee species richness. *One Earth*, 4(1): 114–123. https://doi.org/10.1016/j.oneear.2020.12.005

honey bee, *Apis mellifera*, in the Mediterranean. Long-tongued bees (Megachilidae and Apidae) showed a steepening decline from 2000 onwards, whereas declines in short-tongued bees started earlier (Andrenidae and Halictidae) or later (Colletidae).

Geographic distribution and abundance are also considered to define a species' conservation status using IUCN criteria, a process that was also applied to assess bumble bee species. In 2008, 84 species of bumble bees were evaluated according to the IUCN Red List criteria (based on abundance and geographical distribution), and 150 species (58 percent of the known species) were evaluated in 2018 (Cameron and Sadd, 2020).[3] Outside of bumble bees, abundance and population data for wild bees are missing for nearly all species in all regions.

### Europe

In a meta-analysis of long-term observations across Europe over 110 years, Kerr *et al.* (2015) found that bumble bees consistently failed to track warming through time at their northern range limits, lost range at their southern range limits and (in the case of southern species) shifted to higher elevations. Climate change-driven extinction rates in bumble bees have been found to greatly exceed rates of colonization in Europe, thereby contributing to severe declines in species richness across the region (Soroye *et al.*, 2020).

In 2014, the IUCN European Red List for bees shows that 37 percent of bee species had declining populations (excluding Data-Deficient species), 9 percent (of all species) were classified as Threatened, and 57 percent were Data-Deficient (meaning that their risk status could not be assessed) (Nieto *et al.*, 2014; IPBES, 2016). An update of the European Red List for bees is planned for 2021–2024. Cameron and Sadd (2020) in their global assessment of bumble-bee health found that 21 percent of the 63 European bumble-bee species were threatened.

In the United Kingdom of Great Britain and Northern Ireland, 37 percent of 137 wild bee species analysed declined in occupancy between 1980 and 2016, while 20 percent increased; the average trend across the species was a 25 percent decline (Powney *et al.*, 2019). The declines were greatest between 2006 and 2013, and the average trend across species has since stabilized.

Europe is currently piloting a regional pollinator-monitoring scheme (see Box 6 and Section 4.3.4) that includes wild bees and will be conducted in all European Union (EU) member states from 2022 onwards (Potts *et al.*, 2021)

### Central Asia

A literature search covering the period after the publication of the IPBES (2016) pollinator assessment did not find any additional studies covering this region. Cameron and Sadd (2020) in their global assessment of bumble-bee health did not have data to assess the risk status of bumble bees in North Asia (68 species) or West Asia (73 species). In terms of impacts of change on pollinators in these regions, Gallai *et al.* (2009) identified Middle East Asia, Central Asia and East Asia as the regions that were most vulnerable to pollinator losses (based on an estimate of the contribution of pollinators to the production of the top 100 global crops) but did not address overall species richness and diversity in Central Asia, despite its having been identified as one of the top five global hotspots for bee species richness (Kuhlmann 2005; Bystriakova *et al.*, 2018). Orr *et al.* (2021) state that 79 percent of Africa and Eurasia, which encompasses Europe and Asia, including central Asia, is "completely undersampled" when it comes to bee species richness.

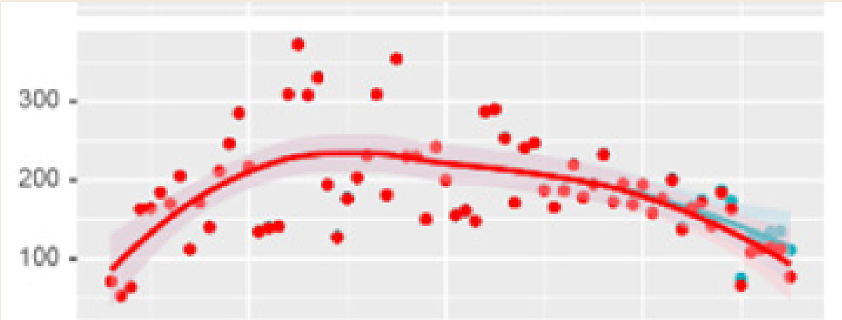
### Africa and the Near East and North Africa

The IPBES (2016) pollinator assessment recognized that a lack of information on species distribution and abundance in Africa precluded any general conclusion of the status of wild pollinators in the region. Following the IPBES pollination report at the twentieth meeting of the CBD's Subsidiary Body on Scientific, Technical and Technological Advice (CBD, 2016a) requested a regional report for Africa on the topic of pollinators, pollination and food production, which was presented later in 2016 at the thirteenth meeting of the Conference of the Parties (COP) to the CBD (CBD, 2016b). This report confirmed that there was no "comprehensive assessment of the status and trends of pollinators and pollination services in Africa."

Based on an analysis of GBIF records, Zattara and Aizen (2021) addressed this knowledge gap by looking at species richness by region and found that Africa's bee species richness has declined since the 1980s. Studies have also continued at national and subnational levels in Africa and the Near East and North Africa. For example, Boustani *et al.* (2021) produced the first annotated checklist of the wild bees of Lebanon; the authors found a total of 573 bee species, but estimated that the total bee species richness is probably closer to 700 bee species. Along with the first-ever national bee checklist, Boustani

[3] Please see Figure 2 in Cameron & Sadd, 2020 for more details.

**Figure 2. Trends shown in the Global Biodiversity Information Facility records for Asia**




*Notes*: The number of occurrence records from the GBIF suggests that decline in pollinator fauna in Asia might have started two or three decades earlier. The left two rows of plots show number of yearly bee records and species in GBIF (blue: full dataset; red: specimens-only dataset); the right two rows show Chao's interpolation/extrapolation curves based on the specimens-only dataset grouped every ten years (idecades) for the period 1946-2015 and bar plots of the asymptotic estimates of richness by idecade for the same period (error bars mark upper and lower 95 percent confidence intervals).

*Source*: modified from Zattara, E.E. & Aizen, M.A. 2021. Worldwide occurrence records suggest a global decline in bee species richness. *One Earth*, 4(1): 114–123. https://doi.org/10.1016/j.oneear.2020.12.005

*et al.* (2021) provide information about local bee distributions and flower records. Aside from these national and subnational studies, no further regional studies covering Africa, or the Near East and North Africa, have been published since 2016.

### Asia and the Pacific

The IPBES (2016) report states that the Asia and the Pacific region is deficient in long-term data on the population trends of wild bees. This conclusion was reinforced by Orr *et al.* (2021) in a study that scanned 5 800 000 public bee-occurrence records.

Cameron and Sadd (2020) report a decline of bumble-bee fauna in Asia and highlight that data deficiencies still exist in the region. The results from Cameron and Sadd (2020) demonstrate and support the idea that there should be more research on bees in Asia. Earlier studies in the region include Williams and Osborne (2009), which, referring to Yang (1999) and Xie *et al.* (2008), suggested that some Chinese bumble-bee species had declined. The same paper reported that there were no known records for *Bombus genalis* and *B. irisanensis* in the Eastern Himalayas for the period since 1983 or for *B. atripes*, *B. sporadicus* anywhere in Asia for the period since 1995. Few records were available for *B. abnormis*, *B. angustus*, *B. braccatus*, *B. makarjini*, *B. mirus*, *B. monozonus* and *B. simillimus* for the period since 1980.

Most studies of pollinator status and trends are local, for example a review of wild bees was investigated for the state of Rajasthan, India (Kumar *et al.*, 2022). A study of community knowledge in Eastern India (Smith *et al.*, 2017) reported declines in several wild solitary bee species. The same study also reported a decline of *Apis dorsata* populations in the study region. Sihag (2014) reported significant declines of *A. dorsata* populations in North West India; the number of migrating colonies of *A. dorsata* in northwestern India fell by half between 1984 and 2012.

### Latin America and the Caribbean

The status and trends of wild bees in the Neotropical region are less well understood than those in North America. Surveys in Brazil have gathered data on the local bee biodiversity and the annual cycles of bee species. Three methodologies have been applied: (i) use of standardized protocols to evaluate bee richness (Pinheiro-Machado *et al.*, 2002); (ii) use of species distribution models, determining potential areas of species occurrence and projecting pollinator assemblages in protected areas (Giannini *et al.*, 2020) and in general, outside protected areas (Giannini *et al.*, 2015; 2017; Krechemer and Marchioro, 2020; Maia *et al.*, 2020; Martins *et al.*, 2015); and (iii) use of data repositories such as GBIF to analyse trends of pollinators for the region (for example, Zattara and Aizen, 2021).

The first bee-monitoring protocol in Brazil was established in the 1960s (Sakagami *et al.*, 1967) at a grassland site in Southern Brazil. The area was almost pristine at the time of the first survey, and after 40 years bee richness had decline by 22 percent overall and by 50 percent in the case of large species (Martins *et al.*, 2013). Cardoso and Gonçalves (2018) assessed the negative environmental impacts of human activities in a metropolitan area in Southern Brazil by comparing data from a bee community in the 1980s to data from the same colony in 2015 and found that bee richness declined by 45 percent over this period and that the relative abundances of species changed. In the case of ground-nesting bees, the same urban area saw a 35 percent decline in species richness, a 95 percent decline in nest abundance and a 24 percent decline in phylogenetic diversity between 1955 and 2018 (Pereira *et al.*, 2021).

Nemesio (2013) reports a decline of orchid bees in Atlantic Rainforests in Brazil. Storch-Tonon and Peres (2017) suggest that declines of orchid bees in the Amazon are caused by forest fragmentation. Declines of orchid bees have also been reported in forests in Panama (Vega-Hildago *et al.*, 2020). A robust dataset of multifunctional ecological traits (body size, flight range, distribution, crop pollination, sociality and nesting) for mountainous areas in the Eastern Amazon of Brazil includes 222 bee species (Borges *et al.*, 2020). In the same area, Eastern Amazon of Brazil in the Carajás National Forest, Giannini *et al.* (2020) produced the first bee checklist for the area in addition to using species distribution models with bee occurrence under different climate change scenarios; their projections show that 95 percent of bee species will decline in occurrence area because of climate change and "only 15 to 4% will find climatically suitable habitats in Carajás" by 2050 and 2070.

### North America

There is enough evidence to determine that wild and managed bees are declining across the United States of America (Koh *et al.*, 2016; Durant and Otto, 2019). Despite this, there are calls for more systematic and standardized monitoring in North America in order to accurately assess bee status and trends (LeBuhn *et al.*, 2013, Koh *et al.*, 2016; Durant and Otto, 2019).

A report published in 2007 by the National Research Council's Committee on the Status of Pollinators in North America (CSPNA, 2007) stated that:

> There is evidence of decline in the abundance of some pollinators, but the strength of this evidence varies among taxa. Long-term population trends for several wild bee species (notably bumble bees) and some butter-flies, bats, and hummingbirds are demonstrably downward. For most pollinator species, however, the paucity of long-term population data and the incomplete knowledge of even basic taxonomy and ecology make definitive assessment of status exceedingly difficult.

The report indicated that the status and trends of very few pollinator species were being monitored in North America. Bumble bees (*Bombus* spp.) are an exception in that there are relatively more studies on them (Cameron *et al.*, 2011). The IUCN Red List assessments for bumble bees found that 26 percent of North American species were threatened (Cameron and Sadd (2020) (Figure 3).

Since the CSPNA (2007) report was published, several studies have looked at wild pollinators in North America, but these have been smaller-scale undertakings. Koh *et al.* (2016) assessed the status and trends of wild-bee abundance and their potential impacts on pollination services across North America, using a spatial habitat model, national land-cover data and expert knowledge. They concluded that using spatial habitat models is justified given that wild-bee populations are largely determined by the spatial distribution of habitat resources within their foraging range and found that between 2008 and 2013 modelled bee abundance declined across 23 percent of the land area of the United States of America. This decline was found to be associated with land conversion and intensification of natural habitats to row crops.

Mathiasson and Rehan (2019) examined the status and trends of wild bee species in New Hampshire, United States of America, over a 125-year time span; using museum data and models, they found 14 bee species were decreasing and 8 bee species increasing in terms of relative abundance. In the same state (New Hampshire), bumble bee (Bombus) records were examined and significant declines of several bumble bee species were found over a 150-year time period (Jacobson *et al.*, 2018).

Work on specific groups of bees has also been conducted in North America. For example, Young *et al.* (2015) studied the status and trends of mason bees, which are more vulnerable to extinction than other bee taxa (e.g. bumble bees). Over a quarter of the 139 native mason-bee species (27 percent) are considered at risk in North America; none of these bees are extinct, due to lack of evidence, but 14 species have not been recorded in recent decades.

There has been no comprehensive assessment of the bee species of Mexico. Based on a review of approximately 60 papers on bee biodiversity, Urbán-Duarte *et al.*, (2021) concluded that 2 063 bee species, belonging to 151 genera, had been reported in Mexico. Yurrita *et al.* (2017) modelled the geographical distribution of 11 stingless-bee species (Melipona) in Mexico and confirmed that there was a lack of information for some species and that taxonomic revision and robust baseline information were needed. As in the United States of America, it is easier to study the status and trends of wild-bee species on a smaller scale, as has been done, for example, in soybean systems in southern Mexico (Ruiz-Toledo *et al.*, 2020). Mexico's National Strategy for the Conservation and Sustainable Use of Pollinators (Estrategia Nactional para la Conservacion y Uso Sustentable de los Polinizadores - ENCUSP) (Government of Mexico, 2021) presents background material on the current state of the country's pollinators (including bees).

Canada's Committee on the Status of Endangered Wildlife in Canada (COSEWIC)[4] has prepared seven status reports.[5] To date, COSEWIC has conducted 88 status reports on arthropods, and seven have been on wild bees; of those seven, five have focused on bumble bees: *Bombus pensylvanicus* (American bumble bee); *B. terricola* (yellow-banded bumble bee); *B. occidentalis* (western bumble bee); *B. affinis* (rusty-patched bumble bee); and the parasitic bumble bee *B. suckleyi* (Suckley's cuckoo bumble bee). The other bees for which status assessments have been conducted are *Lasioglossum sablense* (Sable Island sweat bee) and *Epeoloides pilosulus* (the *Macropis* cuckoo bee, one of the rarest bees in North America [Sheffield and Heron, 2018]). Smaller-scale studies on the status and trends of wild bees in Canada have included the survey conducted in a small area in Thunderbay, Ontario, by Fredenburg *et al.* (2021), which reported the presence of 64 wild-bee species from 17 genera and five families. Many studies that have focused on wild-bee diversity in specific agroecosystems in Canada, for example blueberry (Cutler *et al.*, 2015) and apple (Sheffield *et al.*, 2013) systems.

[4] https://www.cosewic.ca/index.php/en-ca
[5] According to the COSEWIC website, a status report is "a comprehensive technical document that compiles and analyses the best available information on a wildlife species' status in Canada. It contains information on the basic biology of a wildlife species, as well as information on a wildlife species' distribution in Canada, population sizes and trends, habitat availability and trends, and threats to the wildlife species." They are commissioned by the COSEWIC through an open competition process.

Recent technological developments may make assessing the status and trends of wild bees in North America (and beyond) easier; for example, molecular tools and genomics are often used in North America to understand bee diversity (Drossart and Gérard, 2020) and identify why bee populations may be declining (Grozinger and Zayed, 2020; Grozinger and Flenniken, 2019; Cameron and Sadd, 2020).

Among the drivers of change for pollinators in North America, global change effects are a real challenge for conservation, and species range shifts are predicted to occur (Kammerer *et al.*, 2021; Soroye *et al.*, 2020).

**Gaps in knowledge on the status and trends of wild bees**

Data on bee distributions are highly heterogeneous (Orr *et al.*, 2021), with records largely missing from most of Asia, Africa, the Near East and parts of South America (Figure 3). Data on abundance and populations are generally lacking globally.

The status and trends of most wild-bee species in most parts of the world are not covered by long-term international or national monitoring, although a scheme is being rolled out in Europe. IUCN Red List assessments for bees are limited to one regional assessment (Europe) and several national assessments (mainly in Europe), and one bee group (bumble bees) globally.

### 1.1.2. Status and trends of wild non-bee invertebrate pollinators

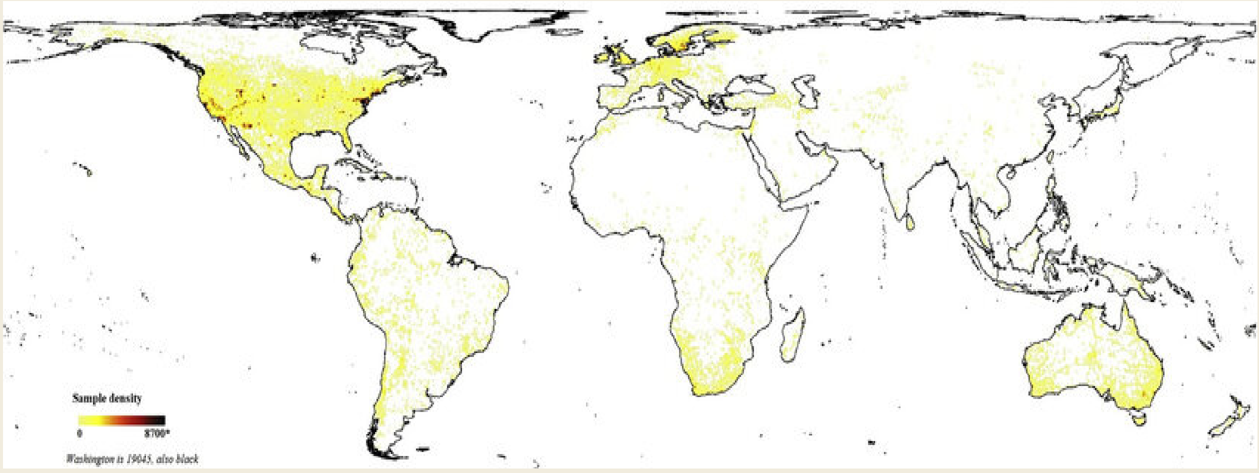
Although bees often have a higher profile, flies, wasps, butterflies, moths and beetles are also important invertebrate pollinators.

**Flies**

The physical and behavioural traits of flies (Diptera) – notably their diverse forms, abundance (usually), mouthpart characteristics, body size and hairiness – make them particularly good pollinators (Ollerton, 2017; Cook *et al.*, 2020). They are key pollinators of both wild and domesticated plants (Rader *et al.*, 2016; Rader *et al.*, 2020). However, there are relatively few datasets of Dipteran population sizes, distributions or trends. Currently, Diptera are considered the least diverse of the four main invertebrate pollinating orders (the other three being Lepidoptera, Coleoptera and Hymenoptera), but this may change as more research reveals the full diversity of pollinating flies and their ecological roles (Ollerton, 2017).

Pollinating fly taxa are very rich and diverse (Raguso, 2020), but studies on their interactions with flowers

**Figure 3. Public database spatial coverage and sampling density**




*Notes*: Given on a 25-km$^2$ grid. Transparent areas are unsampled, while darker colours indicate more intense sampling. Sampling effort is clearly higher in developed countries although, even in these areas, the most-sampled areas are highly localized.

*Source*: Orr, M.C., Hughes, A.C., Chesters, D., Pickering, J., Zhu, C.-D., & Ascher, J.S. 2021. Global patterns and drivers of bee distribution. *Current Biology*, 31(3): 451–458.e4. https://doi.org/10.1016/j.cub.2020.10.053.

are in their infancy (Rader *et al.*, 2020). They include the following groups: generalist pollinators (e.g. syrphids, bombyliids, anthomyiids and tachinids), which are present in many habitats and often dominant in alpine and Arctic habitats; specialized pollinators of deceptive plants whose flowers mimic brood-sites (drosophilids), faeces (muscids) or carrion (sarcophagids and calliphorids); and specialized long-tongued pollinators (e.g. nemestrinids and tabanids in South Africa) (Raguso, 2020). In addition, small flies (e.g. sciarids and mycetophilid fungus gnats) may be key pollinators of species-rich genera of orchids (e.g. Dracula, *Bulbophyllum, Pleurothallidinae*) and plants in the genus *Aristolochia* (Raguso, 2020). The status and trends of most of these fly species remain completely unknown. Flies can pollinate in colder or windy weather conditions when honey bees or other wild bees are not foraging and pollinating (Brittain *et al.*, 2013). This is indicated by shifts from bee to fly pollinator assemblages along elevational gradients (McCabe and Cobb, 2021). Flies are recognized as important insects among the suite of pollinators to any one crop, and many have encouraged more research beyond single species pollinators for crops (e.g. honey bee) (Cook *et al.*, 2020; Raguso, 2020) – ensuring the successful and adequate delivery of pollination services includes those from flies.

To date, the group of Diptera that have received the most attention in pollination studies is the Syrphidae (hoverflies) (Orford *et al.*, 2015). This attention paid to flies (research) allows for status assessments (Biesmeijer *et al.*, 2006; Carvalheiro *et al.*, 2013; Keil *et al.*, 2011; Wotton *et al.*, 2019; von Königslöw *et al.*, 2021), although mostly in Europe and the United States of America (Klein *et al.*, 2012; Menz *et al.*, 2019). Members of the Syrphidae serve as pollinators, and the adults and their larvae often control insect pests (Tenhumberg, 1995). Their contribution to pollination could be substantial, as migratory hoverflies can be remarkably abundant in some temperate areas: for example, nearly 2.7 billion hoverflies are estimated to have migrated (on their way to Europe) over a 300-km radius area of southern England between 2000 and 2009, transferring considerable quantities of pollen over large distances (Wotton *et al.*, 2019).

Trends in the species richness of syrphid flies appear to vary with scale. At scales of 10 km × 10 km and larger, syrphids exhibited no decline in species richness in Belgium, Great Britain and the Kingdom of the Netherlands between 1930 and 1990, and there was also no detectable reduction in species richness between 1990 and 2009 in Great Britain and the Kingdom of the Netherlands; hoverfly richness increased in Belgium during that time (Carvalheiro *et al.*, 2013). At finer scales (1 km × 1 km), however, there was an estimated loss of seven syrphid species per km2 between 1980 and 2013 (Powney *et al.*, 2019). In Germany, a comparison of results from surveys in 1989 and 2014 from six protected areas revealed a 23 percent decline in species richness at a seasonal level and an alarming 82 percent loss at a daily level, suggesting marked implications for pollination (Hallmann *et al.*, 2021). This study also detected an 82 percent decline in hoverfly biomass and an 89 percent decline in hoverfly abundance over the same period at the study sites (Hallmann *et al.*, 2021). In southern England, an analysis of Syrphid (hover)fly abundance data obtained through radar monitoring over a period of ten years suggested no sign of abundance declines, although longer timescales may be needed to detect trends (Wotton *et al.*, 2019).

The only Dipteran listed as endangered in the United States of America is the Delhi Sands flower-loving fly (*Rhaphiomidas terminatus abdominalis*), a habitat specialist of the southern Californian dunes, which has been threatened by development of its habitat and is now very restricted (Kingsley, 2002). Observation of adult *Rhaphiomidas terminatus abdominalis* over five years at a 3.7 hectares preserve concluded that their numbers were stable (Kingsley, 2002), but longer studies and surveys of areas outside preserves are also needed. The genus *Rhapiomidas* has 27 species, all with very small distributional ranges, usually restricted either to aeolian sand dunes or to loose alluvial sands; nine are endemic to a single dune system (Dam *et al.*, 2019), suggesting that species in this group may be vulnerable to habitat transformation. These factors, along with an overall decline in invertebrates (Cardoso *et al.*, 2020) and the small geographical area for which data exist, indicate that there is an important gap in monitoring. In addition to traditional monitoring methods, new technologies such as radar and video (Menz *et al.*, 2019) may yield information on the status and trends of migrating species.

The conclusions on status and trends of pollinators in the IPBES (2016) pollinator assessment were based on a few large-scale studies and many inferences from local studies. The information on hoverflies and other pollinating flies was even more fragmented and incomplete than that on wild bees and (managed) honey bees. Since 2016, substantial progress has been made, particularly on the status of hoverflies, but still mostly in western Europe and North America.

Climate change is predicted to affect pollinators and their interactions with plants, particularly in alpine and Arctic regions. In Greenland, flowering seasons decreased by 3.7 days per decade between 1996 and 2016, and this was associated with a decline in the abundance of flies, which are the dominant flower visitors in the region (Høye *et al.*, 2013). Over 20 years of monitoring (1996 to 2016), several invertebrates species in the North Atlantic region of the Arctic, including important fly pollinators, have declined, while others show no clear shifts (Gillespie *et al.*, 2020). Notably, the abundance of 16 species of muscid flies (many of which are pollinators in the high Arctic) in Greenland decreased by 80 percent over this period, for both common and rare species (Loboda *et al.*, 2018). These landscapes are relatively undisturbed, but recent climate change is likely to be the main driver of change in fly communities, with fly abundance linked to summer temperature shifts in some species.

Non-native species may replace declining native species, with greater non-native fly abundance potentially meaning that landscapes with more agriculture and less natural habitat have better pollination services; this was, for example, found to be the case in a study on fly pollination of pak choi in New Zealand (Stavert *et al.*, 2018).

### Wasps

Wasps as a group are perhaps not usual pollinators for most plants, but there are fascinating cases of specialized pollination systems of sexually-deceptive orchids (genus *Chiloglottis*) and the thynnine wasp *Neozeleboria cryptoides* (Schiestl *et al.*, 2003), orchids attracting prey-hunting wasps by emitting green-leaf volatiles similar to those emitted by leaves in response to herbivore damage (Brodmann *et al.*, 2008) or that have evolved to supply nectar to spider-hunting wasps (Pompilidae) that then carry the pollinaria on their feet (Johnson, 2005).

Little work has been done on trends in the abundance of pollinating wasps, although a study in the United Kingdom that used data from 20 sites for the period between the 1920s and 2012 to assess the effects of landscape change on pollinator richness found that 75 percent of sites had experienced a significant decline in the species richness of pollinating wasps, driven by land-cover changes within the sites themselves and the surrounding landscapes (Senapathi *et al.*, 2015).

Perhaps the best-known wasp pollinators are the fig wasps, obligate pollinators that spend their larval stage within the fruit of fig (*Ficus*) species. Given that Ficus supply crucial resources to numerous other species, these pollinators are key. Gene flow prevents fixation of deleterious mutations within populations and ensures maintenance of genetic variation. Fig wasps, aided by the wind, are capable of carrying pollen on average over 80 km and at times up to

160 km (Ahmed *et al.*, 2009). This facilitates gene flow (Deng *et al.*, 2020).

There seem to be no assessments of the population status and trends of fig wasps. Although most Ficus spp. pollinators remain undescribed, and the degree of host fidelity is not as strict as once thought, the conservation status of *Ficus* species may yield some insights into the status and trends of fig-wasp species. Of the 337 *Ficus* species assessed by IUCN,[6] 2.4 percent are classed as Critically Endangered, 7.7 percent as Endangered, 6.5 percent as Vulnerable and 2.1 percent as Near Threatened. More than half the populations considered Endangered or Near Threatened are decreasing (Table 1).

### Beetles

Beetles are considered to be among the "big four" orders of pollinating insects, and there are estimated to be more than 77 000 beetle species that visit flowers (Ollerton, 2017; Wardhaugh, 2015). This number is likely to rise as new flower-visiting beetle species (Dombrow and Colville, 2020) and novel floral sexual deceptions (Cohen *et al.*, 2021) are discovered. In Brazil, over 90 percent of species within the family Annonaceae have beetles as key pollinators (Blanche and Cunningham, 2005; Jenkins *et al.*, 2015; Pinheiro Saravy *et al.*, 2021). Another example is the prominence of beetles as main pollinators in oil-palm pollination (Greathead, 1983; Tuo *et al.*, 2011; Li *et al.*, 2019).

There seem to be no studies on the status and trends of pollinating beetles. However, beetles belonging to the families Curculionoidea, Cleroidea, Cucujoidea and Tenebrionoidea are important pollinators of cycads (Toon *et al.*, 2020), and many of the interactions are highly specialized. Given that many of these species rely on cycads as brood sites and that more than half of the cycad species on the IUCN Red List are considered to be at risk (Mankga and Yessoufou, 2017), this suggests that beetle species associated with these species may also be under threat. The Red List assessment for 307 species of cycad demonstrated that the populations of nearly 74 percent of these species are decreasing, and explicitly linked possible pollinator extinction or very low pollinator abundance to nine of the declining species, although "reproductive failure" is recorded as a threat for many more species (Rutherford *et al.*, 2013).

Monkey beetles (Scarabaeidae, Hopliini) are among the most important pollinators of Asteraceae and Aizoaceae in the Succulent Karoo (Mayer *et al.*,

**Table 1. IUCN Red List status of *Ficus* species for which assessments have been completed**

| | **Percentage threatened** |
|---|---|
| ***Critically Endangered*** | **2.4** |
| Decreasing | 25.0 |
| Unknown | 75.0 |
| **Data-Deficient** | **5.9** |
| Decreasing | 10.0 |
| Unknown | 90.0 |
| **Endangered** | **7.7** |
| Decreasing | 57.7 |
| Unknown | 42.3 |
| **Least Concern** | **75.4** |
| Decreasing | 7.5 |
| Stable | 76.8 |
| Unknown | 15.7 |
| **Near Threatened** | **2.1** |
| Decreasing | 57.1 |
| Unknown | 42.9 |
| **Vulnerable** | **6.5** |
| Decreasing | 31.8 |
| Stable | 9.1 |
| Unknown | 59.1 |

*Notes:* Values in bold reflect the percentage of species within each threat category; non-bold values reflect the percentages of these species considered to be decreasing, stable or unknown. A total of 337 *Ficus* species for which assessments have been completed were used for this analysis.
*Source:* IUCN Red List version 2018–22.

[6] https://www.iucnredlist.org/

2006) and Fynbos of South Africa. The country has about 1 040 described species of monkey beetles, belonging to 51 genera (Colville *et al.*, 2018). Madagascar has approximately 250 species (Colville *et al.*, 2002). Fragmentation (Donaldson *et al.*, 2002) and heavy livestock grazing (Colville *et al.*, 2002) can disrupt monkey-beetle pollinator guilds, although monitoring data are needed.

Beetles may be the second most important pollinating group of insects in tropical forests, after bees (Wardhaugh, 2015). Further examination and research of beetles and their plant-pollinator interactions, especially in tropical forests, would allow some estimation of status and trends of these species and their potential for delivering pollination services.

### Butterflies and moths

Rader *et al.* (2016) report that Lepidoptera visited the flowers of almost all the crops investigated in a global review of crop pollination. Lepidoptera is a highly speciose order, with just under 160 000 described species (Kawahara *et al.*, 2018). Of those, roughly 140 000 have mouthparts that suggest they are flower visitors (Ollerton, 2017). Given that about 800 new species, primarily moths, are found each year, the total number of extant species may approach half a million (Kristensen *et al.*, 2007). Between 75 and 85 percent of Lepidoptera are moths (Kawahara *et al.*, 2018), yet most monitoring work has focused on butterflies. Moths are clearly important to ecological networks and their roles need further research (Devoto *et al.*, 2011; Hahn and Brühl, 2016; Oliveira *et al.*, 2004). Moth larvae have specialized associations with their hosts, particularly in the tropics (Forister *et al.*, 2015), and so trends in their distribution and abundance can provide a lot of information about the state of ecosystems.

Most assessment of Lepidoptera (mostly butterflies) has been done in the Northern Hemisphere; trends tend to be negative. For example, data on butterflies and burnet moths spanning the period between 1750 and 2018 across Baden-Württemberg, Germany, show significant declines in the relative abundance of most species, with marked declines occurring from the 1950s onwards, particularly for species with specific habitat requirements (Habel *et al.*, 2019). Butterfly and burnet-moth monitoring for the period between 1840 and 2013 in a 45.4-ha area of grassland in Bavaria that received protection in 1992 revealed declines in species richness from 117 to 71 over the 173-year period, with marked declines in habitat specialists and species associated with habitats on low-nutrient soils (Habel *et al.*, 2016).In another study in Germany, a 70 percent decline in species richness in butterflies and burnet moths was recorded in a comparison of point-in-time data from 1972 and 2001 in the calcareous grasslands (Wenzel *et al.*, 2006).

Elsewhere in Europe, significant declines in butterfly species richness were recorded for the Kingdom of the Netherlands, Belgium and Great Britain when comparing 1950–1969 to 1970–1989 and, although the rate of decline dropped between 1990 and 2009 in the Kingdom of the Netherlands, declines in Belgium and Great Britain remained as severe (Carvalheiro *et al.*, 2013). Biomass estimates show a variable pattern, however. Moth biomass estimates from Great Britain showed substantial between-year changes in biomass, but no difference in mean biomass from 1967 to 1982 compared to 2008–2017 (Macgregor *et al.*, 2019). However, the trend of biomass across all traps from 1967 to 2017 showed a significant decline (Macgregor *et al.*, 2019). These fluctuations over time point to a need for long-term and continuous monitoring to enable detection of trends in abundance.

In Europe, butterflies are one of the few taxonomic groups for which there are harmonized European monitoring data (EEA, 2012). This allowed the development of the EU Grassland Butterfly Indicator, which serves as a proxy indicator for the state of biodiversity in the EU. The indicator is generated from empirical data (observation data and field work) for 17 widespread and specialist grassland butterflies in 16 EU countries (Van Swaay *et al.*, 2019).

The Kingdom of the Netherlands, the United Kingdom and the Flanders region in Belgium have greater higher proportions of their butterfly species classed as Extinct or Threatened according to Red List criteria than the rest of Europe (Warren *et al.*, 2021). In the Flanders region of Belgium, nearly 30 percent of butterfly species are extinct and, in the 15 years between 1992 and 2007, abundances declined by 30 percent (Warren *et al.*, 2021). In the Kingdom of the Netherlands, one-fifth of species have become extinct, and abundances have declined to half those recorded in 1990 (Warren *et al.*, 2021). In the United Kingdom, 8 percent of resident species are now extinct, and overall abundance has declined by half since 1976 (Warren *et al.*, 2021). An assessment of the butterflies of Italy concluded that, of the 289 butterfly species assessed, one had become regionally extinct and 18 (6.3 percent) were considered threatened, although most species were considered stable (Bonelli *et al.*, 2018). For Europe as a whole, over 18 percent of species assessed were classed as Threatened or Near Threatened as of 2010, although 47 species were not included in the assessment (van Swaay *et al.*, 2011). The main drivers of decline are habitat loss and degradation, and chemical pollution, with climate change associated with changes in distribution latitudinally (Warren *et al.*, 2021) and altitudinally (Roth *et al.*, 2014).

High species turnover with altitude has also been shown in northern Chile, where butterflies were also shown to be sensitive to aridity (Despland, 2014), pointing to possible ramifications of climate change. Monitoring on Mount Kinabalu, Borneo, found average altitude increases for butterfly presence of 67 m over 42 years (Chen *et al.*, 2009). Tropical species may be particularly sensitive to changes in climate, as species have evolved with less variation in temperature than is found in other regions (Janzen, 1967). In North America, analysis of monitoring data collected by citizen scientists between 1993 and 2018 indicated that trends in butterfly abundance were heterogeneous during this period, with hotspots of increase and decrease associated with climate, although there was an overall tendency towards decline (Crossley *et al.*, 2021). Populations of *Vanessa cardui* were found to fluctuate with climate fluctuations on both shorter (El Niño) and longer (Pacific Decadal Oscillation) time scales (Vandenbosch, 2003).

National assessments allow some insight into the status and trends of Lepidoptera. In New Zealand, approximately 10 percent of butterfly species were assigned to the Extinct, Threatened, At Risk or Data-Deficient Red List classes as of 2015 (Hoare *et al.*, 2017). Of 614 known species of Australian butterfly, 26 (4.2 percent) are categorized as being at high risk of extinction in the next 20 years (Geyle *et al.*, 2021). In Japan, 15 percent of butterfly species were classed as Threatened as of 2007, with the abundance of some species having declined by more than 80 percent (Nakamura, 2011). Of the 199 described butterfly species in the Republic of Korea, 20 were classed as Threatened as of 2011 (Choi and Kim, 2012). A recent assessment of butterflies in South Africa reported that among the 800 species considered, three were classed as Extinct, 7 percent as either Critically Endangered or Endangered, and 3 percent as Vulnerable or Near Threatened (Mecenero *et al.*, 2020). Although about 89 percent of species were classed as Least Concern according to Red List criteria, almost 8 percent of these were classed as either rare or extremely rare according to an additional categorization based on distribution or specialization (Mecenero *et al.*, 2020).

### 1.1.3. Status and trends of managed invertebrate pollinators

#### The western honey bee

The western honey bee, *Apis mellifera*, is the most important managed bee for both honey production and, increasingly, crop pollination (Aizen *et al.*, 2020). *Apis mellifera*, an Old-World species native to Eurasia and Africa, has been introduced into every single continent, except Antarctica (Schneider *et al.*, 2004) and is involved in the pollination of about 80 percent of all crops (Klein *et al.*, 2007). Whether managed or feral, this bee species can account for more than two-thirds of the visits to the flowers of a diversity of temperate and tropical crops, including apple, coffee, grapefruit, macadamia, sunflower and soybean, among others (Aizen *et al.*, 2020). A recent report shows that the species can be conditioned to efficiently pollinate valuable crops such as a kiwi fruit that do not produce nectar and are commonly pollinated mechanically by spraying pollen on flowers (Sáez *et al.*, 2019; Wurz *et al.*, 2022).

Trends in the total number of the western honey bees are difficult to estimate because of the high abundance of wild colonies of this social bee in certain regions, particularly across the Neotropics, where the invasive African honey bee (*Apis mellifera scutellata*) has become extremely abundant (Aizen *et al.*, 2020). On the other hand, wild colonies of *Apis mellifera* in Europe, where many of the 31 subspecies of this domesticated bee originated, are vanishing because of nesting site shortages, hybridization and the transfer of pathogens from managed populations to wild populations (Requier *et al.*, 2019). However, despite dwindling numbers of wild honey-bee colonies in Europe, *Apis mellifera* has increased its dominance in the Mediterranean Basin over the last 50 years (Herrera 2020), probably because of increased beekeeping and a much stronger decrease in the abundance and diversity of hundreds of non-managed bee species. In fact, because of the increasing rarity of thousands of bee species, *Apis mellifera* seems to have increased its relative abundance worldwide (Zattara and Aizen 2021).

Data compiled by FAO (FAOSTAT, 2019) suggest a long-term increase of about 85 percent in the number of managed hives worldwide during the last approximately 60 years (1961–2018 (Osterman *et al.*, 2021, Figure 4), despite a bump in the early 1990s associated with the dissolution of the Soviet bloc (Aizen and Harder 2009a). However, trends differ greatly among continents, with a more or less continuous increase in the number of hives of about 150 percent in Africa from 1961 until around the year 2019, and a vigorous and continuous increase of over 300 percent in Asia between the early 1960s and the present, due in particular to an increase in the number of hives in China and, to a lesser extent, in the Islamic Republic of Iran, India and Türkiye (IPBES, 2016). The Americas also had a

### Box 1. Colony collapse disorder – an example of interacting stressors

Colony collapse disorder (CCD) is a syndrome that affects honey-bee (*Apis mellifera*) colonies, leaving a low number of adult bees (workers) while still sufficient food and brood are in the hive and no obvious reason for mortality (Oldroyd, 2007). The first large-scale losses of honey bees occurred in the winter of 2006/2007 in the United States of America (vanEngelsdorp *et al.*, 2008) and were characterized by the following traits: rapid loss of adult workers, lack of dead worker bees near the hive and the absence or delayed presence of common hive pests (Cox-Foster *et al.*, 2007). After examining over 60 variables for cause of hive death, vanEngelsdorp *et al.* (2009) concluded that there is no single cause of CCD. Affected colonies had "higher pathogen loads and were co-infected with a greater number of pathogens" than the control groups.

*Source*: Cox-Foster, D.L., Conlan, S., Holmes, E.C., Palacios, G., Evans, J.D., Moran, N.A., Quan, P.-L. *et al.* 2007. A Metagenomic Survey of Microbes in Honey Bee Colony Collapse Disorder. *Science*, 318(5848): 283–287; vanEngelsdorp, D., Jr, J.H., Underwood, R.M. & Pettis, J. 2008. A Survey of Honey Bee Colony Losses in the U.S., Fall 2007 to Spring 2008. *PLOS ONE*, 3(12): e4071. https://doi.org/10.1371/journal.pone.0004071; vanEngelsdorp, D., Evans, J.D., Saegerman, C., Mullin, C., Haubruge, E., Nguyen, B.K., Frazier, M. *et al.* 2009. Colony Collapse Disorder: A Descriptive Study. *PLOS ONE*, 4(8): e6481. https://doi.org/10.1371/journal.pone.0006481

long-term positive trend, albeit a modest increase of somewhere below 20 percent, despite the strong decline in the numbers of hives recorded in the United States of America in the mid-2000s (Aizen and Harder 2009a) and in Argentina in the last few years (de Groot *et al.*, 2021). The figures for Europe clearly reflect the decrease in the number of hives associated with the dissolution of the Soviet Bloc in the early 1990s (IPBES, 2016), and those for Oceania reflect an increase of more than 100 percent since 2010 associated with a rapid increase in the number of hives reported by Australia (FAOSTAT, 2019). Still largely unquantified is the relatively recent global phenomenon of rapidly increasing urban beekeeping, an activity presumed to have sizable sociological and ecological consequences (Egerer and Kowawik, 2020).

Honey-bee management for crop pollination is based on the principle that "more is always better". However, in most cases yield becomes saturated or even decreases when crop fields are overstocked with hives (Rollin and Garibaldi, 2019). Thus, in order to maximize crop productivity and reduce economic costs and environmental impacts, management decisions should be based on response curves of yield as a function of hive density for different crops and crop varieties (Russo *et al.*, 2021). Specific guidelines for constructing these yield-to-bee curves have recently been developed (Garibaldi *et al.*, 2020). Because of inconclusive evidence, a deeper understanding of the direct and indirect effects of honey bees and other managed bees on wild plants and pollinators is needed (Mallinger *et al.*, 2017).

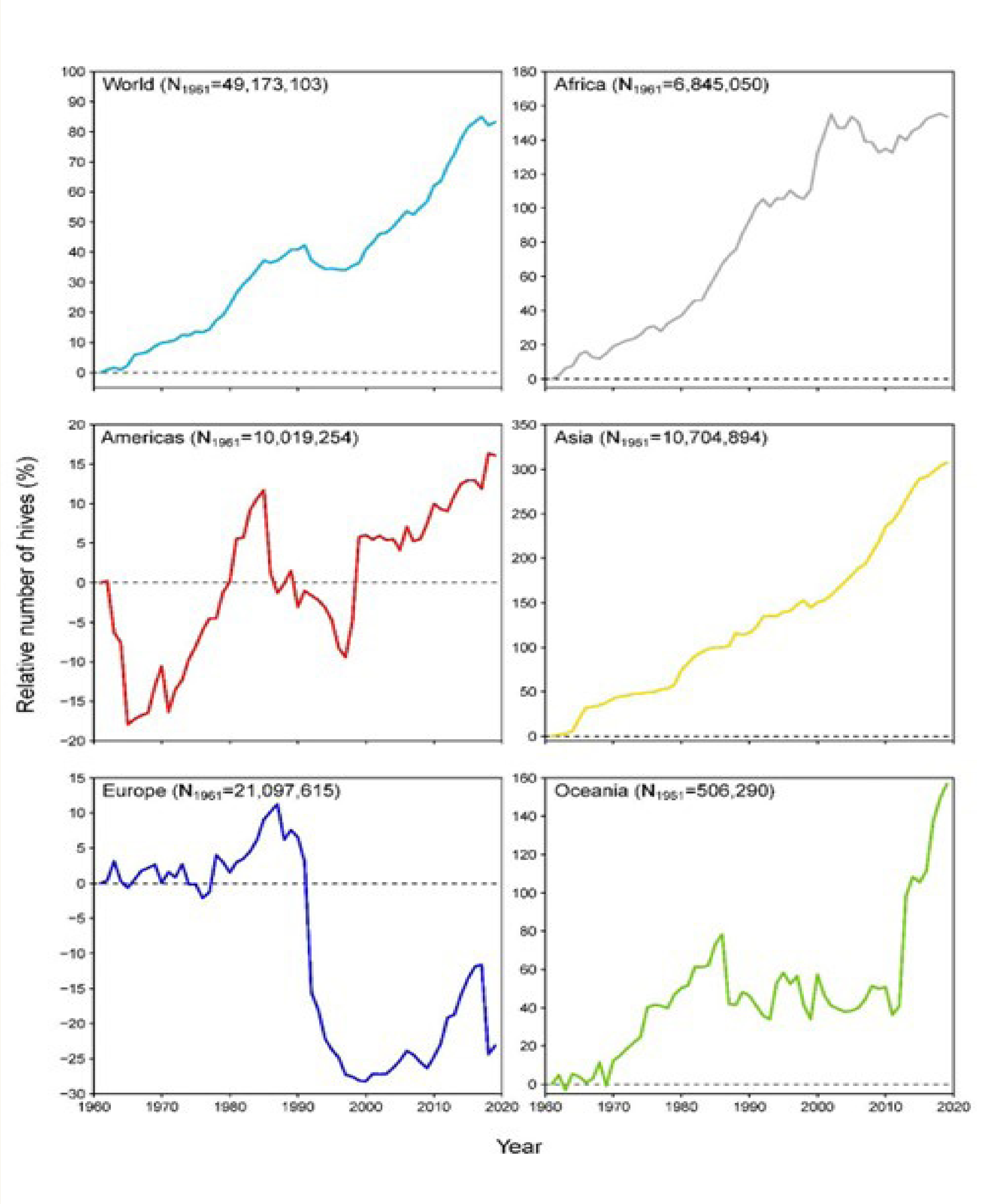
Changes in honey-bee hive numbers are driven by a variety of geopolitical, economic and biological factors, including diseases (Aizen and Harder, 2009a,b; Steinhauer *et al.*, 2018). Multidisciplinary research is therefore needed to disentangle the factors behind the heterogeneity in observed trends among countries and regions.

Threats include colony collapse disorder (CCD) (Box 1), a condition that is hard to define clearly and whose underlying causes are still unknown (Brosi *et al.*, 2017). Infestation with parasites, particularly with the ectoparasite Varroa destructor, probably in combination with other factors such as pesticide exposure, is a major factor in colony loss (Alaux *et al.*, 2010; Brosi *et al.*, 2017; Di Prisco *et al.*, 2013; Goulson *et al.*, 2015).

#### Bumble bees

Bumble bees, *Bombus* species, are an important group of cold-adapted, large social bees that comprises about 260 species, with Eurasia having the largest number of species, followed by North America and South America (Williams 1998). They include probably the most important managed crop pollinators after *Apis mellifera*, notably the European species *Bombus terrestris* and the North American species *B. impatiens* (Reade *et al.*, 2015), which are reared industrially (Aizen *et al.*, 2019, 2020). Bumble bees are more suitable than honey bees for foraging in confined conditions such as greenhouses and pollinating crops, such as tomatoes, eggplants and peppers, that require vibration to release pollen

**Figure 4. Changes in the relative number of managed colonies of *Apis mellifera***




*Notes*: Number of managed colonies of *Apis mellifera* worldwide and in each continent as a percentage of the number in 1961 ($N_{1961}$).

*Source*: Data compiled from FAOSTAT. FAO. 2022. *FAOSTAT*. Rome. Cited 15 June 2023. http://www.fao.org/faostat/en/#data/QA

(Velthius and van Doorn, 2006; Klein *et al.*, 2007). Although about a third of all bumble-bee species seem to be declining (Arbertman *et al.*, 2017), a few species, including the managed ones, are thriving (Cameron *et al.*, 2011, Bommarco *et al.*, 2012). There is a relationship between bumble-bee size and climate change (temperature) and land-use change – which are both drivers of bumble-bee population – although, these drivers do not impact bumble-bee size consistently (Gérard *et al.*, 2020).

Domesticated bumble bees, most notably *B. terrestris*, are involved in a burgeoning international bee trade, which has triggered some extraordinary invasions in Asia, Oceania and particularly South America (Aizen *et al.*, 2019, 2020). The most relevant negative impacts for plants and animals, respectively, seem to relate to flower damage because of flower overvisitation and to pathogen transmission to, and niche displacement of, native congeners (Inoue *et al.*, 2008; Naeem *et al.*, 2018; Aizen *et al.*, 2019, 2020). Sutherland *et al.* (2017) rank bumble-bee invasions associated with the growth of the bumble-bee trade for crop pollination as one of the most important emerging environmental issues likely to affect global diversity. Despite mounting evidence that they have had many negative impacts after becoming invasive in southern South America (Aizen *et al.*, 2019, 2020), importation of B. terrestris into countries such as Chile continues to rise (Figure 5).

The rapid expansion of the bumble-bee trade has been driven by its perceived benefits, mainly for greenhouse crop producers, but its economic and environmental collateral costs have not been adequately considered (Aizen *et al.*, 2020). A thorough assessment of these collateral costs is needed urgently to evaluate the convenience of bumble bee trade outside and within the geographical ranges of the traded bumble bee species (Bartomeus *et al.* 2020). Such risk assessments should not only consider the risk of imported bumble bees replacing native species and becoming invasive, but also the risk of importing diseases.  Based on the precautionary principle and reported empirical evidence of ecological impacts (Aizen *et al.*, 2019; Smith-Ramírez *et al.*, 2018), a ban on international bumble-bee trade in conjunction with promotion of the use of alternative native pollinators for crop pollination inside and outside enclosures would help the conservation of native bee species (Garibaldi *et al.*, 2014).

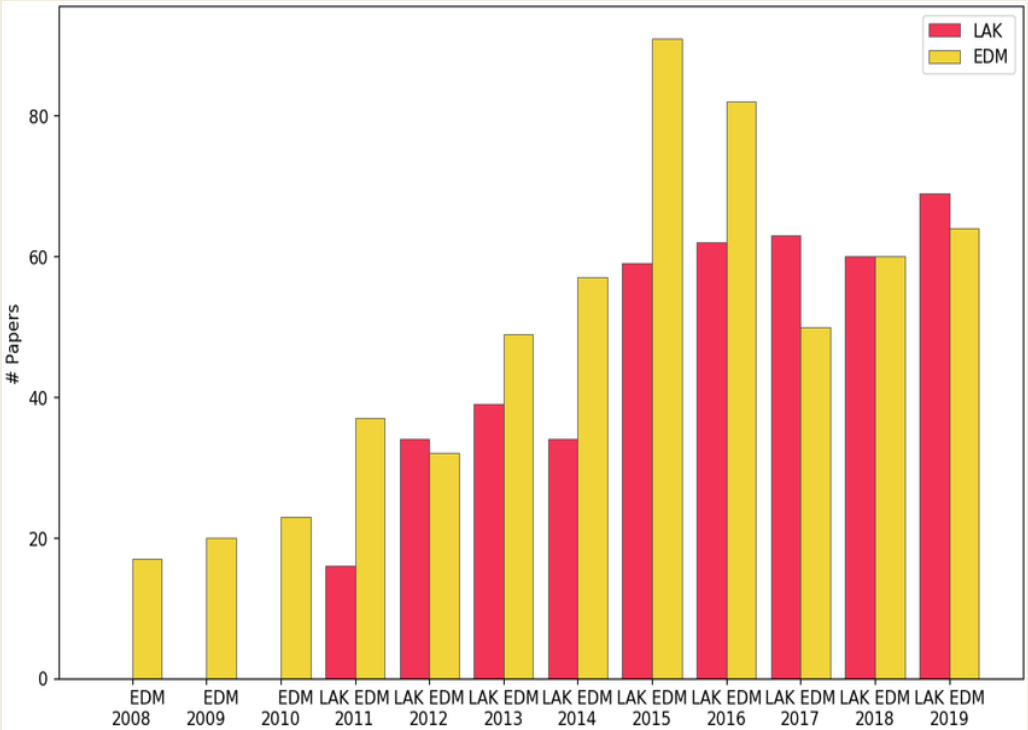
### Stingless bees

Honey bees (11 species) and bumble bees (around 280 species) are well known for their role as pollinators, while supporting healthy ecosystems and human well-being. In comparison, in the tropical and subtropical regions, eusocial stingless bees (around 560 species) (Ascher and Pickering, 2020; Camargo and Pedro, 2013) are significant pollinators and honey producers, and are of major economic importance (Michener, 2007). They are diverse in body size, morphology, behaviour, floral preferences (Bueno *et al.*, 2021), nesting biology, geographic distribution, enemies and nest defence strategies (Grüter 2020). Nevertheless, their nest architecture shows basic patterns allowing for species identification, which facilitate the adoption of appropriate management practices. In the last decade, meliponiculture (the domestication and management of stingless-bee colonies) has increasingly developed in all tropical regions (Cortopassi-Laurino *et al.*, 2006; Kwapong *et al.*, 2010; Jaffé *et al.*, 2015; Heard, 2016; Rattanawannee and Duangphakdee, 2020). Nonetheless, there exists substantial variation in stingless-beekeeping practices among global regions, in accordance with the region's biocultural values (that are commonly derived from traditional knowledge and communities) (Quezada-Euán *et al.*, 2018; Hill *et al.*, 2019) and technical knowledge on colony management for regional bee fauna (i.e. unknown, basic or advanced) (Figure 6). More broadly, such differences are related to a range of cultural, ecological and economic factors that differentiate the world's three major tropical regions (Neotropical, Afrotropical and Indo-Malayan/Australasian), and show the importance of stingless bees and their products worldwide.

Stingless bee breeding varies by region according to the species kept and the commercial focus of the beekeepers (e.g. crop pollination, colony production, honey, pollen, propolis [a substance used by some stingless-bee species for protection against enemies and to improve colony strength and health] or cerumen). Advanced, New advanced management techniques with in vitro queen rearing (Menezes *et al.*, 2013), mating under controlled conditions (Veiga *et al.*, 2017), trap-nests for swarm attraction (Oliveira *et al.*, 2013), honey use and preservation techniques (Souza *et al.*, 2021), and supplementary feeding (Veiga *et al.*, 2017), are spreading to countries where stingless bees are used to promote sustainable development, food security and improvements to the quality of life. As social media has developed, many local stingless-beekeeping associations have been established, and this has helped promote efficient exchange of management practices and local knowledge.

Nuclear markers (e.g. microsatellite loci and single nucleotide polymorphisms [SNPs]) are being used to evaluate the genetic structure of stingless-bee populations (Jaffé *et al.*, 2016). The association of

**Figure 5. Numbers of colonies and queens of Bombus terrestris imported into Chile**




*Notes*: Numbers of colonies and queens of Bombus terrestris imported into Chile since its first introduction in 1997, as of August 2020.

*Source*: Data from the Servicio Agrícola Ganadero of Chile (2020).

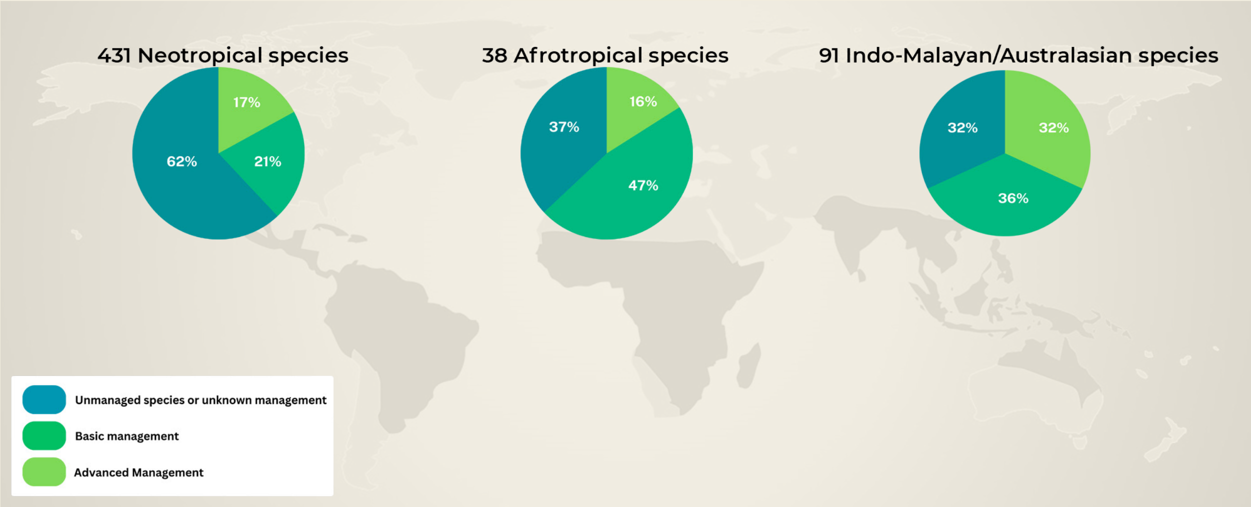
genetic and environmental data (i.e. landscape genomics) offers many possibilities to evaluate the influence of contemporary human-altered landscapes on stingless-bee genetic diversity and functional connectivity, providing useful guidelines for bee breeding and conservation actions (Jaffé *et al.*, 2019). According to Genbank,[7] the genetic sequence database of the United States of America's National Institutes for Health, DNA barcoding (generated from the mitochondrial cytochrome oxidase I [COI] gene) for species identification is known for 86 species of stingless bee across various biogeographical areas. Neotropical species represent about 70 percent of the available data for this genetic marker. Data from other mitochondrial genes are also available and can be used as good markers for species identification and for investigating population variability. Efficient methodologies other than those involving mitochondrial DNA, for example cuticular hydrocarbon profiles and geometric morphometrics of wings, are integrated into many studies on the characterization and mapping of population variability in stingless bees, as they provide fast-track means of investigating biodiversity (Francoy *et al.*, 2011; Ndungu *et al.*, 2017; Galaschi-Teixeira *et al.*, 2018).

Because of their remarkable features, stingless bees are an excellent option for crop pollination and honey production, mainly for smallholders. There are many local species of stingless bees that can be used to improve local livelihoods. Stingless-bee products such as propolis appeal to pharmaceutical companies. The propolis market is very relevant as an income source and is already being supplied by some traditional South American populations.

In order to generate an updated census of stingless-bee species and their management levels, a list with

[7] https://www.ncbi.nlm.nih.gov/genbank

**Figure 6. Broad levels of stingless bees management across tropical regions**




*Notes*: 560 species (431 Neotropical [generic for Central and South America, including the tropical southern part of Mexico and the Caribbean], 91 Indo-Malayan/Australasian [South and Southeast Asia and into the southern parts of East Asia [this includes China, Indonesia as far as Sumatra, Java, Bali, and Borneo] and Australasian is Australia and some neighbouring islands in the Pacific Ocean], 38 Afrotropical [Africa south of the Sahara Desert, the southern Arabian Peninsula, the island of Madagascar, and the islands of the western Indian Ocean]) were each assigned to one of the following categories: 1) unmanaged or management level unknown; 2) basic management; 3) advanced management. Categories were based on the personal experience of experts:1) Afrotropical Region: Alain Pauly (Belgium, United Republic of Tanzania), David W. Roubik (Panama), Kiatoko Nkoba (Kenya); 2) Indo-Malayan/Australasian Region: Abu Hassan Jalil (Malaysia), Shamsul B. A. Razak (Malaysia), Tim Heard (Australia); 3) Neotropical Region: Ayrton Vollet Neto (Suriname), Cristiano Menezes (Brazil), David W. Roubik (Panama), Guiomar Nates-Parra (Colombia), Javier Quezada-Euán (Mexico), Luciano Costa (Brazil), Vera L. Imperatriz-Fonseca (Brazil).

*Source*: Authors elaboration for this background study paper.

valid names of stingless bees was sent to experts in stingless beekeeping. Each expert classified the management level of each species into one of three categories based on his/her experience. In cases where there was disagreement between the experts, the highest of the alternatives was chosen.

The three management levels were as follows:

1. **Unmanaged species or unknown management level.** Species with unknown or poorly described biological features; species that are not suitable for management (e.g. the kleptoparasite *Lestrimelitta* spp., *Oxytrigona* spp. that defend their nests with acids, and necrophagous bees such as *Trigona hypogea*). This group also includes species that are occasionally kept in hives but without any kind of management or product exploitation.
2. **Basic management.** Species kept in simple hives or logs that allow management and exploitation of their products – species that are bred only on a small scale because of specific technical difficulties.
3. **Advanced management.** Species bred in more complex hives that facilitate management activities such as splitting nests or harvesting products: species produced on a small scale but using complex techniques and that do not rely upon wild stocks to grow; species bred on a large scale; species managed for crop pollination.

As stingless beekeeping can be developed in urban as well as in rural areas, the number of stingless beekeepers is projected to increase markedly in the coming decades. Some knowledge gaps must be pointed out, as the transportation of colonies across large geographic areas needs attention and should be regulated by policies to protect subpopulations, avoid the spread of diseases and invasive species. Additionally, the growth of the stingless beekeeping industry around the world should be carefully planned in accordance with environmental regulations to avoid depletion of natural resources. The development of the stingless beekeeping industry must involve public institutions, private initiative and academy on the decisions and regulations to keep it sustainable.

## 1.2 Subspecies-level patterns

### 1.2.1. Wild pollinators

Information on the subspecies of non-*Apis* bees is currently scant. A search of Google Scholar using the key terms “subspecies” and “bees” with a filter restricting the search to publications from 2017 or later yielded 9 600 hits. Of the first approximately 150 results, only five publications were on non-*Apis* bees.

Four of the five publications were on bumble-bee (*Bombus*) subspecies. Three of these focused on *Bombus terrestris* subspecies, of which there are nine (Rasmont *et al.*, 2008). The topics addressed were, respectively, the following: the thermal tolerances of different subspecies *Bombus terrestris* in the context of climate change and extreme temperature variability (Maebe *et al.*, 2021); tracking and identification of three *B. terrestris* subspecies in the Iberian peninsula and some of the risks endemic subspecies face with the commercialization of introduced non-native subspecies (Cejas *et al.*, 2018); and background information on, and history of, commercialized bumble bees (Evans, 2017). The fourth publication on *Bombus* subspecies (Graves *et al.*, 2020) focused on the subspecies of the western bumble bee, *B. occidentalis* and dealt with status and trends, reporting a 93 percent decline in the probability of occupancy of *B. occidentalis* occidentalis in the western United States of America over the preceding two decades. The only other non-*Apis* publication found was a taxonomic paper by Proshchalykin and Maharramov (2020) that investigated osmiine bees in Azerbaijan and reported data for 38 species and four subspecies.

### 1.2.2. Honey bees

Studies on the status of subspecies (geographic races) of invertebrate pollinators are mostly lacking; the subspecies-level information reported here is focused on honey-bee (genus *Apis*) subspecies and honey-bee genetic resources, which are under threat (De la Rúa *et al.*, 2009). Native or indigenous honey-bee subspecies have adapted through evolution to local environmental conditions (as with most local breeds of animals). They have greater resilience and resistance to threats and provide critical reservoirs of genetic resources and diversity.

Based on morphology, phenotypes, behaviour and genetics, five distinct honey-bee evolutionary lineages, and 29 distinct subspecies, can be distinguished, 1) A-lineage – Africa, 2) M-lineage – western and northern Europe and central Asia, 3) C-lineage – central and southern Europe, 4) O-lineage – Caucasus, Türkiye, Near East, Cyprus, Crete and western Asia, and 5) Y-lineage – Arabian Peninsula and Ethiopian highlands (Dogantzis and Zayed, 2018; Carpenter and Harpur, 2021). In western Europe, subspecies *Apis mellifera carnica* and *Apis mellifera ligustica* belonging to lineage C have continuously been introduced (Soland-Reckeweg *et al.*, 2008). As mentioned above, some subspecies are under threat (De la Rúa *et al.*, 2009).

# Chapter 2. Status and trends of drivers of pollinator decline and loss

Land-use change, intensive agricultural management and pesticide use, environmental pollution, invasive alien species, pests and pathogens, and climate change are all direct drivers of pollinator loss (IPBES, 2016). The IPBES pollination assessment did not report on the relative rank (importance) of drivers of pollinator loss. Dicks *et al.* (2021) evaluated the relative importance of eight direct drivers of pollinator loss (pollinator management, pests and pathogens, pesticide use, land management, land cover and configuration, invasive alien species, genetically modified organisms [GMOs] and climate change) as well as the risk this loss poses to human well-being and its subsequent impacts. Across all regions, the direct drivers that were most important were land-use change (land cover and configuration), land management and pesticides. Although the spatial impacts of drivers have been established, limited data availability means that it is still difficult to link pollinator declines to single or multiple drivers.

## 2.1. Land-use change

### 2.1.1. Habitat loss, degradation and fragmentation

Habitat loss, degradation and fragmentation can lead to significant declines in biodiversity, including the biodiversity of vertebrate and invertebrate pollinators (IPBES, 2016). In the case of invertebrate pollinators, most declines in diversity can be linked to associated losses in habitat heterogeneity, which imply decreases in the abundance and diversity of nesting and floral resources. Human-driven fragmentation that creates heterogeneous landscape mosaics can foster bee diversity (Winfree *et al.*, 2007, 2009). Highly generalist, invasive bee species, such as *Apis mellifera* and *Bombus terrestris*, seem more resistant than native bees to the negative effects of habitat fragmentation, degradation and homogenization (Aizen *et al.*, 2020 and references therein). In general, the local characteristics of habitat fragments (e.g. structural complexity, and flower and nesting substrate abundance and diversity) seem to be as important as landscape factors (e.g. fragment size and isolation, and matrix quality) in determining abundance, diversity and composition of invertebrate-pollinator faunas (Proesmans *et al.*, 2019; Lázaro *et al.*, 2020). Functionality of plant–pollinator interactions can be maintained, to a certain extent, in fragmented habitats through opportunistic partner switches (Grass *et al.*, 2018) and differential association of specialists with generalist partners (Ashworth *et al.*, 2004). However, differential loss of specialized pollinators or of certain pollinator functional groups due to habitat fragmentation interactions may erode pollination function and impair the reproduction of many native plants (Aguilar *et al.*, 2019).

Habitat fragmentation is a multifactorial process that entails change in multiple variables, including light, temperature, evapotranspiration, habitat structure, and quantity and quality of nesting and food resources. Disentangling the relative impact of each of these factors on different pollinator groups at both the local and landscape scales is a daunting task. Although there have been some recent attempts to disentangle the effects of these factors on pollinator faunas (e.g. Lázaro *et al.*, 2020), our understanding of the precise causes of the pollinator declines associated with habitat loss and fragmentation is limited. However, it is now clear that local habitat restoration actions, including active enhancement of diverse floral and nesting resources, can have strong positive effects on the diversity of pollinator faunas, even though restoration of the original composition of native pollinator assemblages can prove unrealistic (Menz *et al.*, 2011). At larger scales, reducing pesticide and herbicide loads and promoting habitat heterogeneity, including crop diversification, are recommended (Aizen *et al.*, 2019).

### 2.1.2. Semi-natural habitat and cropland

There is an evidence gap regarding the extent to which the availability of semi-natural habitats for nesting and alternative floral resources – or

**Figure 7. An assessment of the importance of eight major drivers of pollinator decline, for six regions and a global median**


*Notes*: Importance is represented by circle size, reflecting median scores ranging from 1 ("not important") to 5 ("the most important") across nine or ten experts, following three rounds of anonymous scoring (can be found in Supplementary Table 2 of Dicks *et al*., 2021). Drivers are ordered according to effects on score values estimated by proportional odds models (can be found in Supplementary Table 4 of Dicks *et al*., 2021), with higher scoring drivers at the top. All drivers except "pests and pathogens" were scored significantly differently from "climate change", either higher or lower. Degree of confidence is shown by the grey-scale, following the IPBES four-box model based on the confidence score and level of agreement, according to the criteria shown in Table 3 of Dicks *et al*. (2021). No driver was assigned a confidence category of "unresolved". Background shading gradient from yellow to red indicates increasing importance of drivers as a cause of pollinator decline.

*Source*: Dicks, L.V., Breeze, T.D., Ngo, H.T., Senapathi, D., An, J., Aizen, M.A., Basu, P *et al*. 2021. A global-scale expert assessment of drivers and risks associated with pollinator decline. *Nature Ecology & Evolution*, 5: 1453–1461. https://doi.org/10.1038/s41559-021-01534-9

conversely the proportion of cropland – affects pollinator health and pollination service delivery is limited. Pfister *et al*. (2018) reported that, in Germany, a 10 percent increase of the proportion of cropland reduced pollen delivery by bumble bees to pumpkin by 7 percent. Chatterjee *et al*. (2020) showed that reduction of semi-natural vegetation below a threshold level (18 percent and 27 percent of the area within a 2-km radius of the crop fields for mustard and brinjal, respectively) reduces pollen delivery and consequently crop yield.

### 2.1.3. Urbanization

Urbanization is emerging as one of the main drivers of habitat loss and fragmentation, with potential negative consequences both for invertebrate pollinators (Pereira *et al.*, 2021) and for plant pollination (Pauw and Hawkins, 2011). However, bees could be less affected by urbanization than other groups of pollinators such as butterflies and flies (Reeher *et al.*, 2020; Theodorou *et al.*, 2020). In general, relatively high pollinator diversity can be maintained in gardens, habitat remnants and parks, irrespective of the extent of urbanization (Williams and Winfree, 2013; Lanner *et al.*, 2020; Staab *et al.*, 2020). There is now some consensus that plant pollination can succeed in an urban environment and that cities can maintain higher pollinator diversity than areas with intensive agriculture (Baldock *et al.*, 2015; Wenzel *et al.*, 2020). This does not mean that there cannot be sudden collapses of pollination function (Kaiser-Bunbury *et al.*, 2010) or that urban pollinator faunas cannot differ remarkably in composition from those of less-disturbed environments (Geslin *et al.*, 2020). However, urban studies show that invertebrate pollinator faunas can respond positively to local improvements in nesting and floral resources.

In many cities around the world, growing appreciation of insect pollinators has led to the construction of bee hotels (e.g. Fortel *et al.*, 2016) and butterfly gardens (e.g. Di Mauro *et al.*, 2007). However, the extent to which these measures help to preserve native pollinator faunas needs to be elucidated (MacIvor and Packer, 2015; von Königslöw *et al.*, 2019). In any case, knowledge of the nesting and food requirements of specific species can help both foster native pollinator species and discourage the recruitment of exotic species (Geslin *et al.*, 2020).

## 2.2. Conventional intensification and pollinator diversity in agricultural landscapes

Agriculture depends on biodiversity, and many species of organisms (plants, microbes, insects, birds, mammals) depend on sustainable agricultural landscapes – this is key to resilient agricultural systems. It is therefore important to obtain a better understanding of how the biodiversity of functionally important organisms, such as pollinating bees, is declining at the field scale and how the configuration and composition of surrounding landscape elements and ecosystems contribute to pollinator biodiversity and related pollination services.

### 2.2.1. Farm-management practices and pollinator diversity

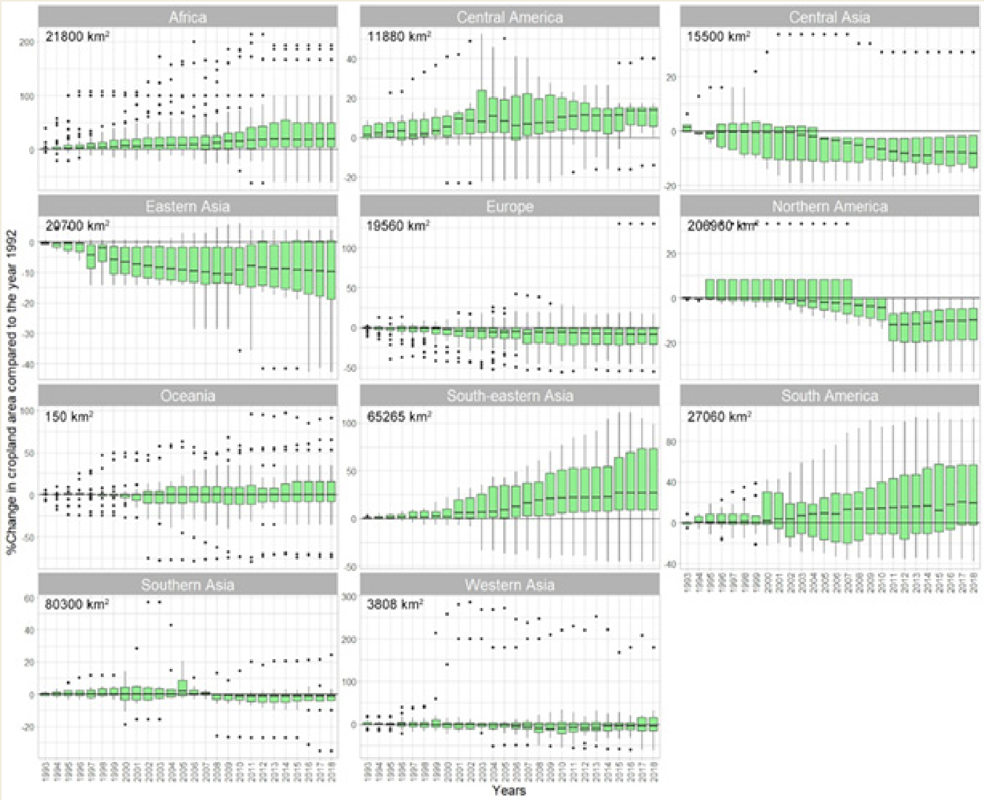
On-farm diversification practices that provide spatiotemporal continuity of floral resources can support pollinator communities (Ullmann, 2015; Guzman *et al.*, 2019; Tamburini *et al.*, 2020). Even for crop systems with pollinators specialized on the focal crop, polycultures of at least two crop species can increase bee activity, abundance and/or bee diversity; a study that compared farms growing squash as a monoculture with farms growing squash and at least one other crop found that the abundance of the specialized pollinators (squash bees) was higher on the polyculture farms than the monoculture farms, while the abundance of honey bees was similar between the polycultures and the monocultures (Guzman *et al.*, 2019). Therefore, crop diversification at the farm scale can even be important for specialist pollinators.

In a two-year tillage experiment in squash farms, Ullmann *et al.* (2015) showed that tillage reduces the number of offspring of ground-nesting squash bees and delays the emergence of the surviving offspring. In contrast, compared to no tillage, the practice of alternating tillage (in every second inter-row) in vineyards can increase wild bee diversity and abundance, showing that pollinator diversity can also be promoted by soil management practices such as tilling when applied in alternating applications (Kratschmer *et al.* 2019). Herbicides are known to have a sublethal effect on bees, but soil management practices and the application of herbicides have not yet been studied. On-farm management in conventional farming systems, like alternate tillage, mowing and mulching, can enhance pollinators, and organic management compared to conventional practice can promote pollinators, although this varies with the scale and intensity of management and landscape context (IPBES, 2016; Samnegård *et al.*, 2019; Tamburini *et al.*, 2020).

### 2.2.2. Loss of pollinator habitats and the importance of landscape features for pollinator diversity

Pollinator decline is well known to be strongly related to the loss of natural habitats (e.g. old-growth rainforest) or semi-natural habitats (e.g. extensive grasslands) (IPBES, 2016; Carrié *et al.*, 2017). Studies have found that the effects of landscape variables on bee diversity and abundance are often as important as, or even more important than, the effects of on-farm practices (Kratschmer *et al.*, 2019; Samnegård *et al.*, 2019). This points to the value of landscape features such as flower patches, hedgerows,

**Figure 8. Cropland area by region, 1993 to 2018**




*Source*: FAO data.

overgrown ditches and trees (single or in groups) for pollinators in agricultural landscapes.

In some parts of the world, flower strips are a commonly used practice to enhance pollinators in agricultural landscapes to counteract pollinator decline. Flower strips have frequently been shown to successfully promote pollinating insects (Burkle *et al.*, 2020; Haaland *et al.*, 2011; Lowe *et al.*, 2021, and, in landscapes dominated by agriculture, pollinators were enhanced also beyond the flower strip itself (Jönsson *et al.*, 2015; Carvell *et al.*, 2017). When flower strips are connected in otherwise intensively cultivated agricultural areas, they produce long-term effects on pollinator diversity (Buhk *et al.*, 2018). Pre-existing perennial semi-natural habitat patches that are rich in flowering plants – hedgerows, for example – help conserve pollinator diversity (Rollin *et al.*, 2019; Ponisio *et al.*, 2019; Li *et al.*, 2020). Little is known about herbaceous habitat patches such as those found on overgrown slopes and vegetation along fences and drainage ditches, which can also be high-quality habitat for pollinating insects in intensive agricultural landscapes (von Königslöw *et al.*, 2022).

### 2.2.3. Farm size, landscape composition and configuration as important factors in mitigating pollinator loss in agricultural landscapes

At the landscape scale, the loss of structural diversity comes along with increasing field size, often as a result of land consolidation programmes and favouring the use of efficient large machinery optimizing cultivation (Fahrig *et al.*, 2015; Batáry *et al.*, 2017; Clough *et al.*, 2020). Smaller farms harbour higher pollinator diversity such as bumble bees than larger farms (Geppert *et al.*, 2020). This is mainly caused by the fact that landscapes with small-scale farms have relatively longer field borders, and this can greatly promote insect biodiversity (Fahrig *et al.*, 2015; Batáry *et al.*, 2017).

Landscape composition is generally expressed as the percentage of natural/semi-natural habitat, and landscape configuration as the density of edges/ecotone, both measured in a given area surrounding the farm (e.g. a 1-km radius), and landscape configuration is expressed as the density of edges/ecotone within such an area (Martin *et al.*, 2019). A recent meta-analysis (Martin *et al.*, 2019) that looked at how these factors affect pollinators in agricultural landscapes in Europe found that 70 percent of pollinator species reached their highest abundances in landscapes with high edge density and that pollination services were 1.7-fold higher in such landscapes than in those with low edge density. Arable-dominated landscapes with high edge densities are productive with a good number of pollinator species (diversity).

The characteristics of agricultural landscapes are critical for pollinators. Key features of pollinator-friendly agricultural landscapes include polycultures rather than monocultures, appropriate soil-management practices and decreasing the farm size (< 2 ha indicated by Clough *et al.*, 2020) by connecting field borders used for semi-natural landscape elements such as long-term flowering herb patches and perennial woody flowering plants. As these landscape elements need to be managed, they need to be incentivized and/or, if possible, used for bioenergy production or additional food production for local markets, for example by including fruit- or nut-producing trees and shrubs in hedgerows. Future research needs to monitor the farms to landscape changes on pollinators for continuing adaptations of such complex pollinator-friendly and productive landscapes.

**Status and trends of agrochemical consumption under conventional intensification**

While more areas have come under cultivation in the developing regions of the world over the last 25 years (Figure 8), different parts of the world have experienced different rates of intensification (Pallegrini and Fernandez, 2018). Various factors associated with agricultural intensification affect pollinator health and plant–pollinator interactions, either directly or synergistically. A meta-analysis (Schulz, 2021) that analysed changes in the use of 381 pesticides over 25 years by considering 1 591 substance-specific acute toxicity threshold values for eight non-target species groups, including pollinators, showed that total applied toxicity in pollinators (and aquatic invertebrates) markedly increased after 2005. The study concludes that these increases were driven by insecticides such as highly toxic pyrethroids and neonicotinoids. It found similar enhanced total applied toxicity for pollinators in genetically modified (Bt) maize production.

Over the last 25 years, trends in the consumption of synthetic agrochemicals have varied differently across different regions of the world. There have been changes in total pesticide consumption (including insecticides, herbicides and fungicides) across different countries of the world (Figure 9). There has been a substantial increase in the total pesticide consumption rate in different areas of the world, for example in Canada, China, Australia and most parts of South America, especially in Brazil. In South America, the trends of agrochemical use have had two peaks, with significant increase in the use of pesticides around the late 1990s and the early 2000s. Around the same time there has also been a significant change in South America where no-tillage practice was adopted on a large scale. From 670 000 hectares of no-till in the MERCOSUR countries (Brazil, Argentina, Paraguay and Uruguay) in 1987, no-till was practised on over 30 million hectares in these countries in 2002. This, in combination with new and more-efficient no-till seeding technology, may have led to a major increase in herbicide use (Derpsch 2008; Bernoux *et al.*, 2006) (Figure 10).

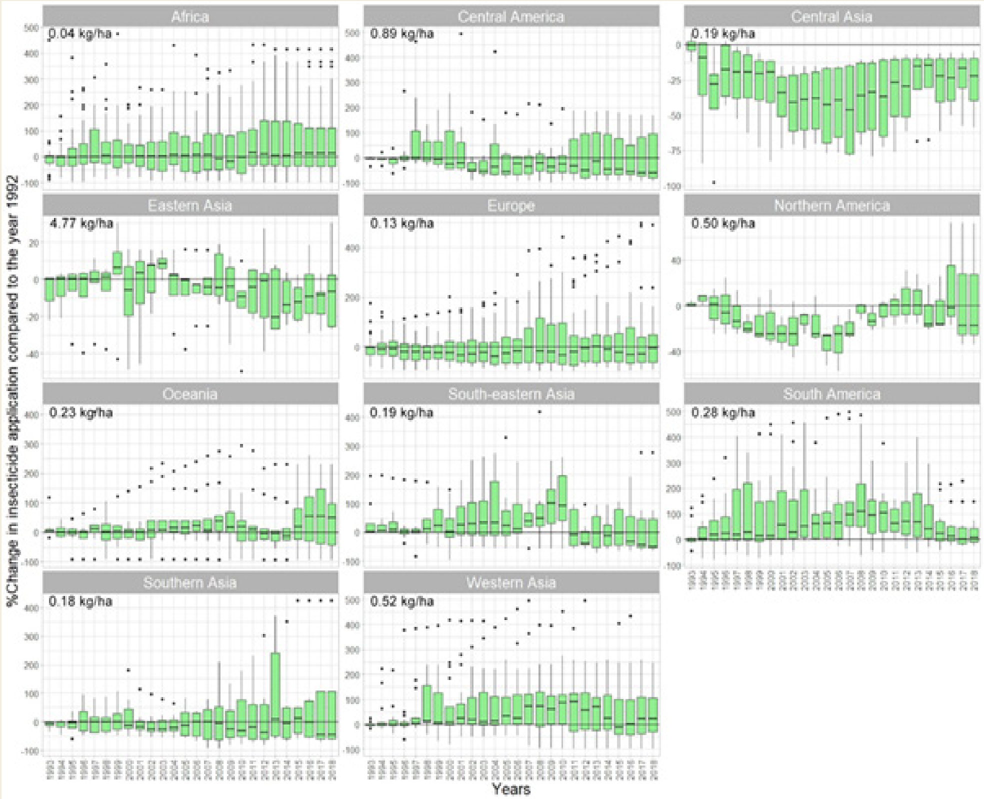
## 2.2.4. Insecticides

Use of insecticides per unit area has grown substantially in certain regions of the world, for example in Oceania and marginally in Africa. Use is declining in the Americas (South, North and Central America) and Europe. A reduction is also apparent in South, Southeast and Central Asia.

It is important to note that the consumption patterns of specific insecticide groups have not remained uniform during this period. For example, there has been significant growth in the use of neonicotinoids in Europe. The trend for the United Kingdom shown in Figure 11 is illustrative of this change. There was a significant increase in neonicotinoid use during the period 1994 to 2016, while use of the other major insecticide types remained the same or plummeted over this period.

A closer look at the pesticide-consumption data reveals intraregional variations. For example, in Africa, the largest increase in insecticide consumption was in the Gambia followed by the United Republic of Tanzania and Ghana. In Central America, Nicaragua and Costa Rica saw the largest increases. In South America, the largest increase was in Ecuador, followed by the Plurinational State of Bolivia. In South Asia, the largest increase was in Nepal, followed by Bangladesh. Bangladesh saw an 89 percent increase in insecticide consumption between 1995 and 2018 and a 118 percent increase in pyrethroid consumption during the same period. Total insecticide consumption, however, fell by 49 percent in India. In Southeast Asia, the largest increase was in Myanmar, followed by Indonesia. In Europe, consumption was

**Figure 9. Relative consumption (per unit area) growth of synthetic insecticides over the last three decades**




*Notes*: Graphs show the median values and the range across different countries in respective regions. Dots indicate outlier values in a region. The regional median values in the base year (1992) are indicated in the insets.

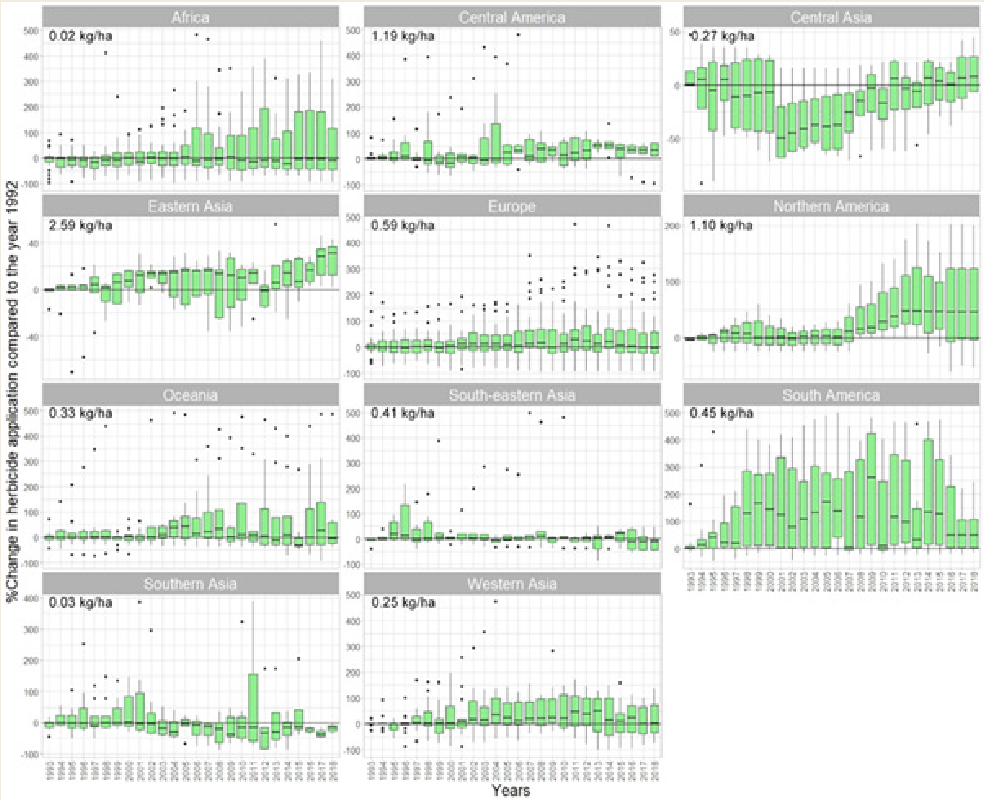
*Source*: FAO data.

highest in the Russian Federation. It is important to note that the volume of pesticides used is not an indication of their environmental impact, but their respective toxicities are.

Recent literature on the effect of insecticide on pollinators is dominated by studies on neonicotinoids, and reports on other insecticide groups, including biopesticides, are relatively less common. Tamburini *et al.* (2021) showed that Sulfoxaflor insecticide and Aazoxystrobin fungicide have no major impact on honey bees but do have major impacts on bumble bees in realistic-exposure semi-field experiments (Tamburini *et al.*, 2021). Reports on the impact of insecticides on non-*Apis* bees are also a glaring gap (Siviter, 2019). However, more studies on non-*Apis* bees are being done (e.g. Klaus *et al.*, 2021). Challa *et al.* (2019) studied the impact of a few widely used biopesticides, for example Azadirachtin, Anonnin, *Beauveria bassiana* and Bt var., on Asiatic honey bees, *Apis cerana*, and found them to be slightly to moderately toxic. de Oliveira *et al.* (2019) studied the impact of Dithiocarbamete on pollinators in sunflower fields in Brazil and reported significantly lower pollinator visitation in plots treated with the insecticide. Long and Krupke (2016) reported that pollen collected by honey-bee foragers in maize- and soybean-dominated landscapes is contaminated throughout the growing season with multiple agricultural pesticides, including the neonicotinoids used as seed treatments. Although the impacts of neonicotinoids are well documented, the mechanistic framework of their possible mode of action is still being investigated. Pamminger *et al.* (2018) suggested that there might be a close ontogenic association between the haemocytes of the insect immune system and nervous systems and that this connection makes the immune system of pollinators and other insects inherently susceptible to interference by neurotoxins, such as neonicotinoids, at sublethal doses (Figure 12).

In a major systematic review and meta-analysis, Siviter *et al.* (2018) concluded that insecticides

**Figure 10. Relative use (per unit area) growth of herbicide, by region and subregion, 1992 to 2018**




*Notes*: The graphs show the median values and the range across countries in the respective regions. Dots indicate outlier values in a region. The regional median value in the base year (1992) is indicated at the top left of each graph.

*Source*: FAO data.

have significant negative effects on learning and memory: (i) at field realistic dosages; (ii) under both chronic and acute application; and (iii) for both neonicotinoid and non-neonicotinoid pesticides groups. Chakraborty *et al.* (2019) reported visual abnormalities and impairment of colour recognition in *Apis cerana* due to chronic insecticide exposure in intensive agricultural areas.

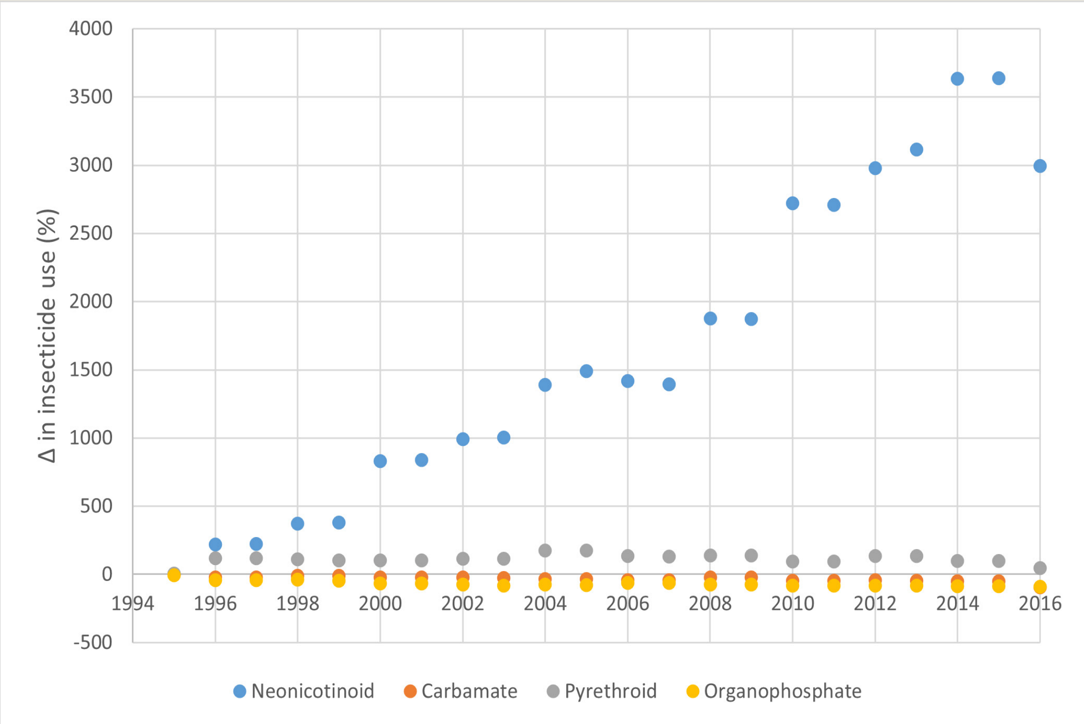
## 2.2.5. Herbicides

Herbicides account for nearly 47.5 percent of all pesticide usage worldwide (Grube *et al.*, 2011; De *et al.*, 2014; Sharma *et al.*, 2019). Herbicide use rose marginally in Africa and in Central America between 1992 and 2018 (Figure 10).

The countries with the highest herbicide consumption in the regions shown in Figure 10 are Mozambique in Africa, Costa Rica in Central America, Uruguay in South America, Canada in North America, the Republic of Korea in Eastern Asia (no data are available for mainland China), Bangladesh in South Asia, Armenia in Western Asia, and Serbia and Poland in Europe.

The impact of herbicides on non-target floral diversity in agricultural landscapes and their consequent indirect impact on pollinator populations have been widely studied (IPBES, 2016). In comparison, the direct impact of herbicides on pollinators has been less studied. Herbert *et al.* (2014) reported a negative impact of glyphosate on learning in honey bees (*Apis mellifera*). However, reports of weeds developing resistance to glyphosate have also surfaced (Heap and Duke, 2017) and use of alternative biotech products and 2,4-D is becoming common. Bohnenblust *et al.* (2016) studied the impact of the synthetic-auxin herbicide- dicamba and 2,4-dichlorophenoxyacetic acid (2,4-D) on pollinators and found that

**Figure 11. Changes in consumption levels of different types of insecticides in the United Kingdom of Great Britain and Northern Ireland, by year, 1994 to 2016**




*Notes*: Dots indicate the change in consumption level of the respective insecticide in the respective year relative to that of 1994.

*Source*: Food and Environment Research Agency, Department for Environment, Food and Rural Affairs (Defra), Government of the United Kingdom of Great Britain and Northern Ireland.

pollinators visited alfalfa crops sprayed with dicamba less frequently. Glyphosate has been shown to affect the microbial community of the bee gut, which in turn increases susceptibility to infection by opportunistic pathogens. Exposure of young worker bees to glyphosate increased mortality among those subsequently exposed to the opportunistic pathogen *Serratia marcescens* (Motta *et al.*, 2018). A meta-analysis by Battisti *et al.* (2020) concludes that glyphosate is toxic to bees. However, there is a crucial gap in our understanding of the sublethal or lethal toxic effects of glyphosate and other herbicides on bees. Furthermore, a recent study suggests that it is the surfactant and not the active ingredient of glyphosate that causes mortality in bumble bees (Straw *et al.*, 2021). Future research should focus on disentangling the toxicity of the different substances and active ingredients in pesticides, including herbicides.

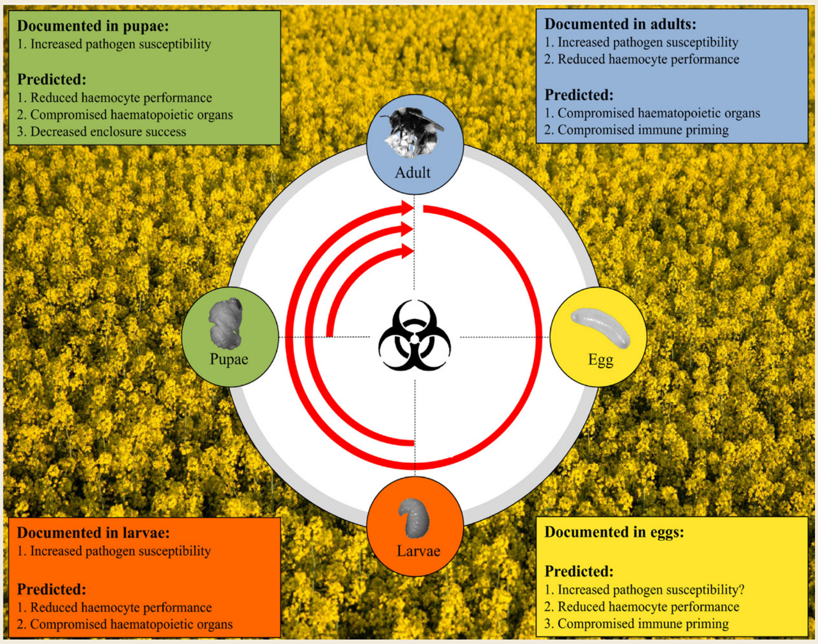
The status and trends of herbicide use should not be examined separately from the sharp rise in herbicide-tolerant weeds, as the issues are tightly linked. Since 1991, 500 species worldwide have been recorded as being herbicide-tolerant. Figure 13 illustrates trends in the numbers of herbicide-tolerant species.

### 2.2.6. Fungicides

South America, Oceania, and Southern Asia have seen substantial rises in fungicide use during the last three decades, while use has plateaued in Africa and North America following a rise (Figure 14).

The leading countries in terms of herbicide consumption include the Gambia in Africa, Costa Rica in Central America, the Plurinational State of Bolivia in South America, Mongolia in Eastern Asia, Bangladesh in South Asia, Armenia in Western Asia, Myanmar in Southeast Asia, and Portugal in Europe.

**Figure 12. Summary of the potential effects of neurotoxic pesticides on pollinator immunity**




*Notes*: Based on results from older developmental stages (late larvae to adult), early developmental stages will most likely suffer from increased pathogen susceptibility, resulting from reduced haemocyte performance during acute infections (spreading number, composition, spreading behaviour, pathogen detection, encapsulation and nodulation). In addition, compromised haemocyte functionality during development (e.g. mobility and migration) may result in complications during the formation of the haemopoietic organs and metamorphosis. The same mechanisms may compromise transgenerational immune priming as well. These effects are likely to be additive, resulting in increasing risk of mortality before reaching adulthood (red arrows). This is a summary of the predicted effects for each developmental stage.

*Source*: Pamminger, T., Botías, C., Goulson, D. & Hughes, W.O.H. 2018. A mechanistic framework to explain the immunosuppressive effects of neurotoxic pesticides on bees. *Functional Ecology*, 32(8): 1921–1930. https://doi.org/10.1111/1365-2435.13119

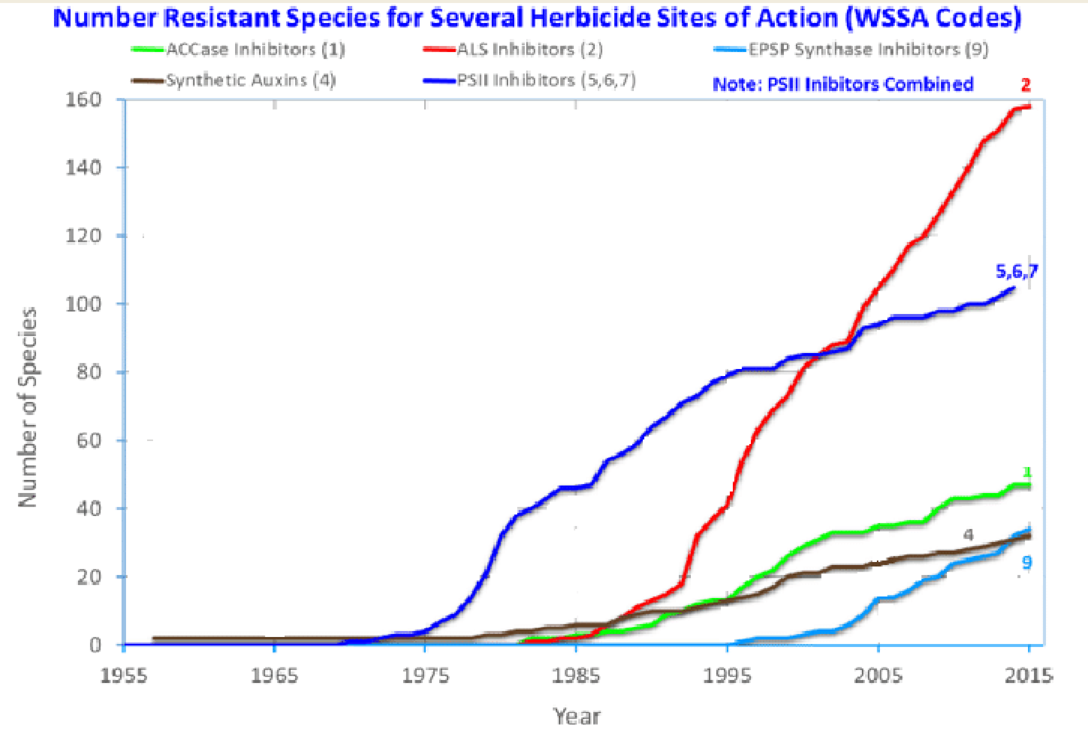
Fungicides, although they seem to lack acute toxicity to insects, may affect bees directly, by altering their metabolism, reproduction and food consumption (Bernauer *et al.*, 2015; Mao *et al.*, 2017), and indirectly, by increasing insecticide toxicity (Sgolastra *et al.*, 2017; Tsvetkov *et al.*, 2017). Fisher *et al.* (2017) studied the synergistic impacts of three fungicides (Iprodione 2SE Select, Pristine and Quadris) on *Apis mellifera* in almond orchards and reported that exposure to Iprodione 2SE Select caused a significant decrease in forager survival and that Iprodione 2SE Select in combination with Pristine and Quadris gave rise to synergistic detrimental effects. Mao *et al.* (2017) showed that Triazole fungicides have an indirect impact on the insecticide detoxification mechanism in honey bees. The same study also reports that honey-bee foragers that consume or are exposed to triazole myclobutanil produce less thoracic ATP and thus have less energy for flight muscles. There have been reports of bees avoiding cranberry fields where fungicide has been applied (Jaffé *et al.*, 2019).

### 2.2.7. Fertilizer

Fertilizer consumption has increased in Africa, Oceania, South America, South and Southeast Asia. (Figure 15).

Nitrogen fertilization has increased in most regions, the maximum growth being in Northern and South America. Leading countries in terms of nitrogen-fertilizer consumption include Botswana and Uganda in Africa, Honduras in Central America, Canada in North America, Paraguay and Ecuador in South America, Mainland China and Japan in East

**Figure 13. Growth in the number of herbicide-tolerant species**




*Source*: Heap, I. 2018. *The International Survey of Herbicide Resistant Weeds.* www.weedscience.org

Asia, Bhutan and Pakistan in South Asia, Thailand in Southeast Asia, Lithuania and Hungary in Europe, and New Zealand in Oceania.

Although there is general agreement about the negative impact of extensive fertilizer use on pollination, the effects of elevated biologically available nitrogen (N) on plant–pollinator interactions have not been well studied (Harrison and Winfree, 2015). The various pathways by which fertilizers can impact plant–pollinator interactions are: (i) alteration of plant species composition; (ii) phenology; (iii) the partitioning of resources to flowers and floral morphology; and (iv) the quantity and nutritional quality of nectar and pollen (David, Storkey and Stevens (2019) (Figure 16). David, Storkey and Stevens (2019) provide an extensive review on the subject. Ramos *et al.* (2018) report that the positive effects of native pollinators on crop yield in Brazilian common bean crop fields were largest when low levels of nitrogen fertilizer were applied. Tamburini *et al.* (2017) report that pollination benefits to sunflower yield were the highest at intermediate levels of nitrogen availability.

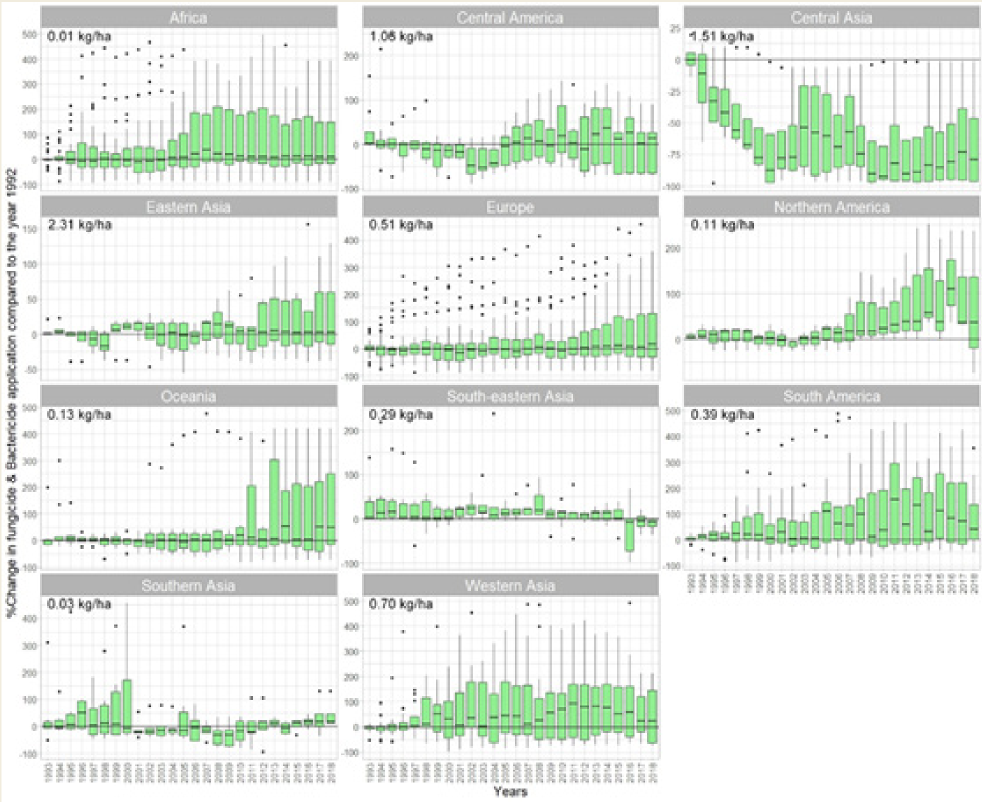
### 2.2.8. Molluscicides

Data on the effects of molluscicides on bees are currently missing in the international scientific literature. There is evidence that no-tillage farming benefits slug populations; a study of the effect of applying a neonicotinoid in such a system found that it did not affect slug populations but reduced soybean yield, thus showing that pesticides applied in such circumstances may not be well targeted (Douglas *et al.*, 2015).

### 2.2.9. Tillage

A citizen-science study has shown significantly increased abundance of squash bees (Eucera pruinose) in no-tillage or reduced-tillage treatments compared to conventional tillage (Appenfeller *et al.*, 2020), but in general the effects of tillage on pollinators are unstudied. Tillage is used as an alternative to the use of herbicides. Studies comparing the effects of tillage to those of other weed-reduction methods on pollinators, pollination and crop production are therefore urgently needed.

**Figure 14. Relative use (per unit area) growth of fungicides, 1992 to 2018**




*Notes*: The graphs show the median values and the range across different countries in the respective regions. Dots indicate outlier values in a region. The regional median value in the base year (1992) is indicated at the top left of each graph.

*Source*: FAO data.

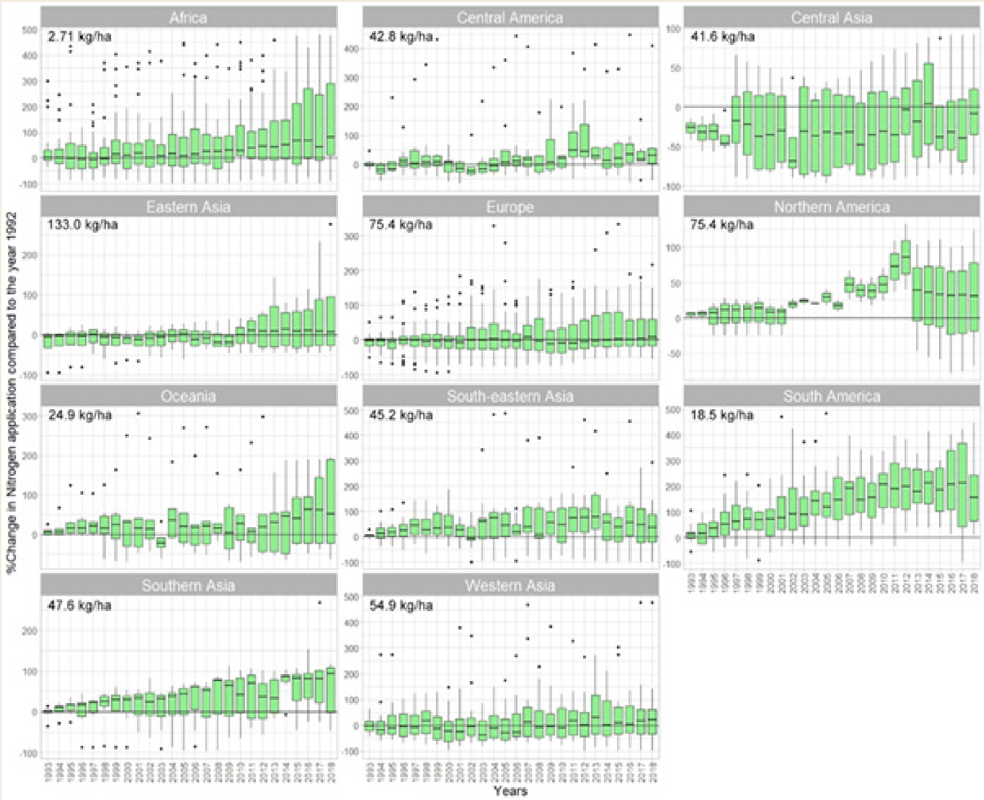
### 2.2.10. Irrigation

There have been hardly any studies of the impact of agronomic practices other than on the use of synthetic chemical inputs on pollination (Lindstrom *et al.*, 2017). Sinu *et al.* (2019) reported a negative effect of sprinkler irrigation on Apis cerana and their pollination services in pumpkin crops but how irrigation influences group-nesting bee occurrences and population development is not known.

## 2.3. Diseases, pathogen introductions and invasive alien species

Species invasions and the novel contact opportunities they create present risks of pathogen host shifts, coinfections and the evolution of virulence with possible detrimental effects on pollinator species lacking immunity or resistance. It is well established that multiple anthropogenic pressures individually and in combination threaten and drive declines in managed and wild pollinators and this includes invasive alien species, parasites and pathogens (Potts *et al.*, 2016; IPBES, 2016; Grozinger and Flenniken, 2019; Cameron and Sadd, 2020; see also Arbetman *et al.*, 2017). Such anthropogenic pressures may extirpate populations or species, alter abundance and dominance, rewire interactions, disrupt species' phenology and distributions at landscape, regional or global levels, and affect species physiology. Global-change impacts may affect disease resistance and pathogen infectivity/virulence and transmission. The spread of native or invasive pathogens within pollinator populations or spillover in the novel pollinator–plant communities that assemble under global changes are likely to pose a future

**Figure 15. Relative consumption (per unit area) growth of nitrogenous fertilizer consumption, 1992 to 2018**




*Notes*: Graphs show the median values and the range across countries in the respective regions. Dots indicate outlier values in a region. The regional median value in the base year (1992) is indicated at the top left of each graph.

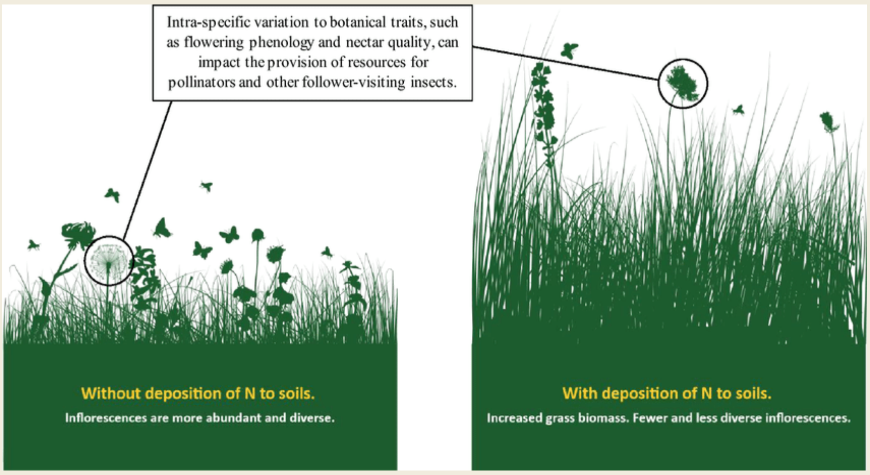
*Source*: FAO data.

threat (Brown *et al*., 2016; Vanbergen *et al*., 2018; Proesmans *et al*., 2021). Pathogen transmission occurs when individual insects share flowers providing nectar and pollen resources (McArt *et al*., 2014) during social interactions (Chen *et al*., 2006) and during mating, which leads to vertical transmission between generations (De Miranda and Fries, 2008; Beaurepaire *et al*., 2020).

Anthropogenic translocations of species often lead to alien species invasions that have severe consequences for plant–pollinator populations and communities (Vanbergen *et al*., 2018; Vanbergen *et al*., 2013; Schweiger *et al*., 2010). Alien pollinators can directly compete with native species or affect them indirectly by introducing novel pathogens (Aizen *et al*., 2020) or enhancing transmission of native pathogens (Cameron *et al*., 2016). Potentially invasive pollinators (e.g. *Bombus terrestris*), which are often introduced deliberately or accidentally via the bee trade into regions outside their native distribution ranges (see below) and are usually highly competitive generalist foragers with an extensive flying period, can profoundly disrupt recipient communities (Aizen *et al*., 2020). Dominant invasive species may push native species to shift onto, and compete for, suboptimal and less-abundant forage plants (Magrach *et al*., 2017), potentially elevating their nutritional stress and pathogen susceptibility.

Invasive alien plant species often provide copious floral resources and so come to dominate pollinator diets and rearrange species interactions in ways that disrupt the structure and functioning of the plant–pollinator network (Hernández-Castellano *et al*., 2020; Albrecht *et al*., 2014). Consequently, the flowers of invasive plants can serve as potential hubs

**Figure 16. The loss of flowering species and dominance of grasses with elevated nitrogen deposition**




*Note*: N deposition alters the landscape and can affect the available food resources for pollinators.

*Source*: David, T.I., Storkey, J. & Stevens, C.J. 2019. Understanding how changing soil nitrogen affects plant–pollinator interactions. *Arthropod-Plant Interactions*, 13(5): 671–684. https://doi.org/10.1007/s11829-019-09714-y

for pathogen transfer within and between species by concentrating pollinator activity and diversity (McArt *et al.*, 2014; Majewski *et al.*, 2019; Graystock *et al.*, 2020). Non-insect pollinated invasive plant species can also concentrate pollinator activity and contact by suppressing native vegetation and limiting the availability of forage plants (Hachuy-Filho *et al.*, 2020). Pathogen spread within a community can be facilitated in various ways including through the structure of plant–pollinator interaction networks (i.e. pathogen host shifts and "modulating disease dynamics" (Proesmans *et al.*, 2021). There is very little evidence on this topic in pollinator epidemiology.

Invasive plants may also increase pollinator susceptibility to pathogens in that the pollen or nectar they supply, while often copious, may be suboptimal and lacking in essential nutrients or containing secondary compounds toxic to certain pollinator species (Tiedeken *et al.*, 2016). In the longer term, invasive alien plants may alter the reproductive success of native plant species, either by facilitating or by competing for insect pollination with co-occurring species (Albrecht *et al.*, 2016). Such processes may reconfigure plant–pollinator assemblages and species interactions, indirectly affecting the likelihood of novel epidemiological interactions among pollinators and plants.

Besides plant invasions, other functional group invasions could indirectly affect pollinator–pathogen dynamics. Invasive non-pollinating insects may be known vectors or novel pollinator pathogens (Dobelmann *et al.*, 2020; Loope *et al.*, 2019). Herbivores, by altering plant biochemistry and pollen quality, may influence pollinator–pathogen interactions and pathogen loads (Aguirre *et al.*, 2020). Alien predators (by consuming pollinators – Laurino *et al.*, 2019) or novel herbivores (by reorganizing the plant community – Glaum *et al.*, 2017) may affect pollinator populations differentially, create new niches or via interactions affect pathogen circulation and interspecific processes (facilitation, competition) governing disease dynamics (Loope *et al.*, 2019). Pollinators may also, in turn, play a role in shaping the transmission of plant pathogens: viruses affect plant chemical signals that recruit pollinators differentially, altering pollination and plant reproduction in ways that ultimately alter communities (Groen *et al.*, 2016). Such changes to food webs are a feature of global change and may either limit pathways of disease propagation or create new ones. However, the evidence needed in order to understand these effects remains unavailable.

An outcome of the trans-continental transport of pollinating bees (bee trade in *Apis mellifera*, but also, for example, *Bombus terrestris* and *B. impatiens*) beyond their native ranges (IPBES, 2016; Vanbergen *et al.*, 2018; Aizen *et al.*, 2020; Graystock *et al.*, 2016) increases the risk of pathogen/parasite transfer to new hosts, and risks of eliciting population declines of native pollinators (Aizen *et al*., 2020; Morales *et al*., 2013; Arbetman *et al*., 2013). The sustained movement by humans of managed honey-bee (*Apis mellifera*) colonies into Asia ultimately resulted in a host shift of the ectoparasitic Varroa destructor mite and the microsporidian Nosema ceranae from sympatric *Apis cerana* populations – and their subsequent worldwide spread (Vanbergen *et al*., 2018; Wilfert *et al*., 2016; Higes *et al*., 2008; Martin and Brettell, 2019).

As part of trade in managed honey bees, the *Varroa destructor* mite, along with a complex of viral pathogens (*Picornavirales*) it transmits among bee hosts, has spread worldwide. This mite, by its direct parasitic feeding, by vectoring viruses, and possibly by suppressing bee immune functions, is among the major global pressures on managed and feral honey-bee colonies (Wilfert *et al*., 2016; Martin and Brettell, 2019; Brosi *et al*., 2017). Parasitism of *Apis mellifera* by *Varroa destructor* exacerbates transmission and prevalence of several RNA-viruses infecting the honey bee (Wilfert *et al*., 2016; McMahon *et al*., 2015). Weakening of the host's immune system by combined parasite and pathogen infections may induce rapid micro-evolutionary changes that increase virulence (Loope *et al*., 2019; McMahon *et al*., 2015; Manley *et al*., 2019). The *Varroa* host shift may have elicited micro-evolution in the virulence of deformed wing virus (DWV) strains implicated in colony losses (Loope *et al*., 2019; McMahon *et al*., 2015). There are also signs of pathogen spillover or sharing between managed bee populations and wild pollinators and other insects (Dobelmann *et al*., 2020; Loope *et al*., 2019; Arbetman *et al*., 2013; Wilfert *et al*., 2016; Martin *et al*., 2019; McMahon *et al*., 2015; Bailes *et al*., 2018). Such exchanges in a multi-host system elevate the risk of the evolution or ecological emergence of new disease. Such host shifts highlight the risks of species invasions for creating novel species interactions, selective pressure and population or community epidemiology with consequences for arresting pollinator declines (Vanbergen *et al*., 2018). International regulation of bee trade represents an important limit to the emergence of trade-driven emergence of novel pathogens (Aizen *et al*., 2019).

Apart from the risk of emerging disease in previously unaffected regions due to transport of managed bees over large distances, bee management presents additional epidemiological risks. Decreases in managed *Apis mellifera* genetic diversity, caused by selective breeding (Espregueira Themudo *et al*., 2020) may weaken *A. mellifera* immune responses (Youngsteadt *et al*., 2015) resulting in increasing pathogen levels in their population. Managed *A. mellifera* are maintained at higher colony densities than naturally, which together with their dietary supergeneralism, positions them as a central hub or a "superspreader" reservoir host in plant–pollinator networks (Stein, 2011; Bailes *et al*., 2020). They may amplify pathogen loads (Bailes *et al*., 2020) and virulence when coinfected with *V. destructor* (Manley *et al*., 2019; McMahon *et al*., 2016), although recent modelling has cast doubt on this role (Bartlett *et al*., 2019). By potentially outcompeting wild pollinators for scarce food, managed bees may drive nutritional stress in alternative hosts and potentially spread pathogens to them during foraging (Aizen *et al*., 2020; Manley *et al*., 2015; Purkiss and Lack, 2019; Pike *et al*., 2019; Manley *et al*., 2017). This may be a dynamic process, with multiple spillover and spillback events iteratively increasing the risk of pathogen exchanges and the development of novel community epidemiology.

## 2.4. Climate change

Climate change is predicted to impact all of the following: "rainfall distribution, wind patterns, temperature, air pollution and occurrence of extreme weather events, among other environmental changes" (IPCC, 2014; Yuan *et al*., 2023). These changes associated with climate change can, over time, negatively impact pollinators (e.g. reducing their effectiveness) (IPCC, 2022) through various ways such as change or disrupt phenologies (both in plants and insects) (Hegland *et al*., 2009), pollinator presence and abundances (Groom *et al*., 2014; Kougioumoutzis *et al*., 2022; IPCC, 2022), range shifts (Kerr *et al*., 2015; Spooner *et al*., 2018) or leading to species extinctions (Soroye *et al*., 2020; IPBES, 2016; IPCC, 2022). Such effects have been demonstrated over recent decades.

The challenges in studying the impacts of climate change on pollinators are the time lags and impacts not being immediate (i.e. not being apparent for several decades due to "delayed response times" in systems involving plants and insects) (IPBES, 2016; Maebe *et al*., 2021); these systems include our agricultural systems. Measuring the effectiveness of adaptation strategies involving pollination is therefore complex, and a large knowledge gap remains to be filled (Schweiger *et al*., 2010).

The following paragraphs briefly discuss how climate change impacts pollinators in terms of disrupting phenologies, range shifts and species extinctions.

### Phenology

As noted above, studying the impact of climate change on pollinators is complicated by delayed responses in both plants and insects, and by a lack of reliable historical data on phenological shifts. There is evidence that climate change can induce asynchrony between flowers and pollinators, assuming there are no compensating mechanisms (Memmott *et al.*, 2007; Stemkovski *et al.*, 2020; 2023).

Specific plant–pollinator interactions (mutualistic interactions) are at the highest risk of phenological mismatching due to changes in temperature (Bartomeus *et al.*, 2011). Different studies have come to different conclusions about the extent of phenological asynchrony: Polce *et al.* (2014) tested future climate change scenarios and found spatial mismatches between orchards and their pollinators. Other studies examining plant–pollinator interactions report no phenological asynchrony. For example, a study in northeastern North America reported that the phenology of ten bee species had advanced by a mean of 10.4 ± 1.3 days and, when examining rates of advance for plants, they reported bee emergence was keeping pace with shifts in host-plant flowering, but this was among generalist bee species (Bartomeus *et al.*, 2011). Bartomeus *et al.* (2013) looked at phenological synchrony between apple and the native bees that pollinate it and found "extensive synchrony between bee activity and apple peak bloom due to complementarity among bee species' activity periods."

### Range shifts

Pollinator species have shifted their ranges in response to climate change, and this is expected to continue (IPCC, 2022). "The broad patterns of species and biome shifts toward the poles and higher altitudes in response to a warming climate have been observed over the last few decades in some well-studied species groups such as butterflies and bumble bees" (IPCC, 2022). Studies of Bombus species using data and models from Europe (see Box 2) and North America (Sirois-Delisle and Kerr, 2018) show that bumble-bee ranges are contracting (Cameron *et al.*, 2011; Kerr *et al.*, 2015) even under scenarios of high dispersal rates (Rasmont *et al.*, 2015; Sirois-Delisle and Kerr, 2018).

All climate change scenarios reported by the Intergovernmental Panel on Climate Change in 2022 suggest that: "(i) pollinator community composition is expected to change as certain species decrease in abundance while others increase; and (ii) the seasonal activity of many species is projected to change differentially, potentially disrupting life cycles and interactions between species. Changes in composition and seasonality are both projected to alter ecosystem function. In high-altitude and high-latitude ecosystems, climate changes exceeding low-end scenarios (e.g. RCP 2.6) are very likely to lead to major changes in species distributions and ecosystem function, especially in the second half of the 21st century. The rate of change of the climate across the landscape, especially under mid-end and high-end IPCC greenhouse gas emissions scenarios is predicted to exceed the maximum speed at which many pollinator groups (e.g. many bumble bee and butterfly species), can disperse or migrate, in many situations despite their mobility" (IPCC, 2022).

The maintenance of biodiversity is one of the key adaptation measures for conserving pollinators and combat climate change impacts (IPCC, 2014).

## 2.5. Synergistic effects of multiple stressors

Potential interactions between invasive alien species and other global-change pressures may further modify the risk of pollinator disease via synergistic or antagonistic effects (Potts *et al.*, 2016; Cameron and Sadd, 2020; Proesmans *et al.*, 2021; Vanbergen *et al.*, 2013). It should be noted that global-change pressures and their interlinked effects are ultimately caused by common drivers (e.g. human population growth, resource consumption), making it very difficult to disentangle and rank their relative importance (Potts *et al.*, 2016; IPBES, 2016). Most research on multi-stressor interactions affecting bees (mostly the honey bee *Apis mellifera* or the bumble bee *Bombus terrestris*) has been done on nutrition–pathogen–pesticide interactions in experimental settings (Vanbergen *et al.*, 2013; Goulson *et al.*, 2015). Adverse impacts on bee health or performance are often reported from experiments that test the effects of combinations of nutritional stress and pesticides (Tosi *et al.*, 2017), pesticides and pathogens (Dussaubat *et al.*, 2016; Baron *et al.*, 2014; Doublet *et al.*, 2015; Botías *et al.*, 2021) or pesticides and parasitic mites (Straub *et al.*, 2019). Such negative effects are not ubiquitous (Leza *et al.*, 2019; Retschnig *et al.*, 2015), however, and the extent that they scale up to affect populations in real landscapes remains unclear (see references within Cameron and Sadd, 2020). Nonetheless, a recent field study (Centrella *et al.*, 2020) showed how conventional intensive agriculture itself poses a multifactorial risk to pollinators (in this case the solitary bee *Osmia cornifrons*) in the form of reduced dietary diversity that directly affected bee reproduction or health and greater exposure to agrichemical stressors such as pesticides. Another recent field experiment (Zaragoza-Trello *et al.*, 2021)

**Box 2. Pollinators in Europe**

The most up-to-date evidence on the impacts of climate change on pollinators is from the 2022 Intergovernmental Panel on Climate Change report (IPCC, 2022). There is high confidence that the ranges of many groups of pollinators are shrinking in Europe (Rasmont *et al.*, 2015; Kerr *et al.*, 2015; Soroye *et al.*, 2020; Zattara and Aizen, 2021). At the same time, data from Europe, which are relatively good, indicate that pollinators are also declining because of other drivers, such as land-use change, pesticide use, pollution, pests and pathogens, and invasive alien species (IPBES, 2016; Settele *et al.*, 2016; Steele *et al.*, 2019). Projected impacts of climate change on bumble bees across Europe are mixed – but they are greater under 3 °C of global warming level (GWL) (Rasmont *et al.*, 2015). Under all the scenarios for the period (SEDG, BAMBU and GRAS ) up to 2100 considered by Rasmont *et al.* (2015), suitable climatic conditions would still persist in areas such as northern Europe and the mountains of central and eastern Europe, and therefore species richness could increase for some groups of bumble bees, while trends for bumble bees elsewhere in Europe remain unclear (Fourcade *et al.*, 2019; Soroye *et al.*, 2020).

*Sources*: Fourcade, Y., Åström, S. & Öckinger, E. 2019. Climate and land-cover change alter bumblebee species richness and community composition in subalpine areas. Biodiversity and Conservation, 28(3): 639–653. https://doi.org/10.1007/s10531-018-1680-1; IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2016. Assessment Report on Pollinators, Pollination and Food Production. Zenodo. https://doi.org/10.5281/zenodo.3402857; Kerr, J.T., Pindar, A., Galpern, P., Packer, L., Potts, S.G., Roberts, S.M., Rasmont, P. et al. 2015. Climate change impacts on bumblebees converge across continents. Science, 349(6244): 177–180. https://doi.org/10.1126/science.aaa7031; IPCC. 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY, USA, Cambridge University Press. 10.1017/9781009325844; Rasmont, P., Franzén, M., Lecocq, T., Harpke, A., Roberts, S.P.M., Biesmeijer, J.C., Castro, L. et al. 2015. Climatic Risk and Distribution Atlas of European Bumblebees. BioRisk, 10: 1–236; Settele, J., Bishop, J. & Potts, S.G. 2016. Climate change impacts on pollination. Nature Plants, 2(7): 16092. https://doi.org/10.1038/nplants.2016.92; Steele, D.J., Baldock, K., Breeze, T.D., Brown, M.J.F., Carvell, C., Dicks, L.V., Garratt, M.P. et al. 2019. Management and drivers of change of pollinating insects and pollination services. National Pollinator Strategy: for bees and other pollinators in England, Evidence statements and Summary of Evidence. London, UK, The Department for Environment, Food and Rural Affairs. http://centaur.reading.ac.uk/88315/; Soroye, P., Newbold, T. & Kerr, J. 2020. Climate change contributes to widespread declines among bumble bees across continents. Science (New York, N.Y.), 367(6478): 685–688. https://doi.org/10.1126/science.aax8591; Zattara, E.E. & Aizen, M.A. 2021. Worldwide occurrence records suggest a global decline in bee species richness. One Earth, 4(1): 114–123. https://doi.org/10.1016/j.oneear.2020.12.005

that examined multiple stressor effects showed how bumble bee individuals, castes and colonies can be affected, positively and negatively, by the complex interplay between increasing environmental temperature, variable resource availability and pesticide exposure.

Although long acknowledged as a risk, exactly how major direct drivers (land-use change, climate change, disease and invasive alien species) may interact to influence pollinators is still not well understood (IPBES, 2016; Cameron and Sadd, 2020; Vanbergen *et al.*, 2013; González-Varo *et al.*, 2013). It has been postulated that interactions between climate change and invasive alien species affect pollinators (Schweiger *et al.*, 2010) and provide novel epidemiological niches for emerging pathogens (Brown *et al.*, 2016). Anthropogenic changes (conventional intensive agriculture, urbanization) to landscapes and the floral resources they provide (see, for example, references within Kovács-Hostyánszki *et al.*, 2017) are – aside from their direct effects on bee health (Requier *et al.*, 2017) – also likely to influence the chances of alien species becoming established (Vanbergen *et al.*, 2018) and create novel opportunities for the exchange of pathogens within and between pollinator species (Cameron and Sadd, 2020; Proesmans *et al.*, 2021). This interplay of pressures may be realized through changes in abundance or diversity that reshape species interactions and contacts in plant–pollinator–pathogen networks (Schweiger *et al.*, 2010).

Changing climatic niches and trade in bees and pollination services may shift distributions or translocate organisms (hosts or parasites) in ways that alter the mutual exposure of new hosts and pathogens (Vanbergen *et al.*, 2018). Extirpation of populations or species and/or changes to the phenology, abundance and dominance of species because of the effects of land-use change or climate change may split, merge and reassemble communities and species interactions in novel ways that create epidemiological risks and opportunities for the spread of alien species, pathogen host shifts or the evolution of virulence (IPBES, 2016; Proesmans *et al.*, 2021; Schweiger *et al.*, 2010; González-Varo *et al.*, 2013).

Species richness may dilute the risk of interspecific pathogen sharing (Fearon and Tibbetts, 2021), for example by minimizing the contact rate of pathogens with new host individuals or species. Therefore, minimizing the negative impact of land-use intensification on the diversity of pollination systems (Potts *et al.*, 2016; IPBES, 2016; Kovács-Hostyánszki *et al.*, 2017; Redhead *et al.*, 2018) by conserving and restoring biodiversity and habitats may help both to make pollination services more resilient (Potts *et al.*, 2016; Garibaldi *et al.*, 2011; 2016) and to reduce the risk of species invasions and diseases emergence that may erode them (IPBES, 2016). It should be noted, however, that compared to laboratory experiments there remains an overall lack of empirical evidence on the multifactorial risks affecting pollinators and pollination under field conditions (Centrella *et al.*, 2020; Zaragoza-Trello *et al.*, 2021), particularly where invasive alien species and disease are concerned (Cameron and Sadd, 2020; Proesmans *et al.*, 2021). Most of the evidence is therefore either reasonably extrapolated from laboratory studies or deduced from correlative field studies showing the effects of single pressures on pollination systems.

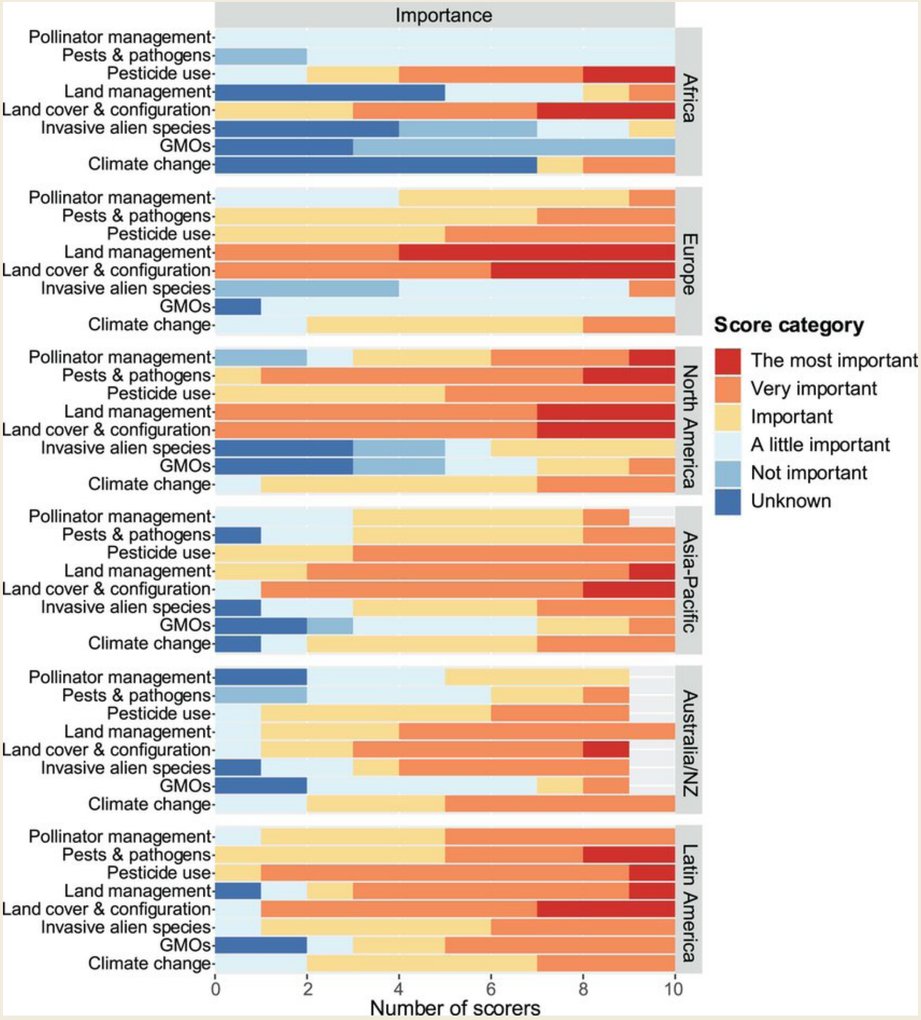
While scientific and policy awareness of pressures on wild pollinators has increased (IPBES, 2016) and led to regulations or initiatives at various levels of governance aimed at protecting pollinators and their habitats, less regulatory attention has been devoted to the diseases of wild pollinators and their interplay with managed bees and environmental change (Table S1 in online version of Proesmans *et al.*, 2021).

The synergistic effects that multiple stressors, such as the insecticides, herbicides and fertilizers etc., used extensively in intensive agricultural landscapes, have on pollinators and plant–pollinator interaction have recently received attention. Dupont *et al.* (2018) studied the effects of herbicides and nitrogenous fertilizers on non-target plant reproduction and their indirect effects on pollination. They report negative impact of glyphosate, nitrogen and their interaction on floral density and flowering phenology. Glyphosate application reduced floral density and delayed flowering with the latter amplified when nitrogen was added. Consequently, there was reduced flower visitation by pollinators and reduction in seed set. In another study, Evans *et al.* (2018) explored the link between pesticide use on pollinator communities and how such exposure might impact parasitic disease transmission. Not only did this study find lower pollinator abundance, group richness and diversity in agricultural sites with higher pesticide use but also found varying prevalence of different parasitic groups (*Ascosphaerea* and Microsporidia) in different pollinator groups (solitary bees, honey bees and flies). Few studies have examined the ways in which parasites and pesticides interact and affect pollinator health and communities.

Wade *et al.* (2019) report that a combination of the insecticide chlorantraniliprole and the fungicide propiconazole were found to have a synergistic adverse effect on *Apis mellifera* larval and adult survival in North American almond orchards. A meta-analysis of 90 studies (Siviter *et al.*, 2021) that looked at the effects of combinations of stressors (agrochemicals, nutritional stressors and parasites) on pollinators found an overall synergistic effect on bee mortality but acknowledged that understanding the mechanisms behind the effect will require further research. Grassl *et al.* (2018) report that a study in Australia found that the neonicotinoid insecticide thiamethoxam and the parasite *Nosema apis* had a synergistic negative effect on the survival of *A. mellifera*. A substantial increase in mortality and a reduction of immunocompetence were observed in workers exposed to both the pathogen and the pesticide.

Iverson *et al.* (2019) studied the effects of the sterol biosynthesis inhibiting (SBI) fungicides difenoconazole, myclobutanil and fenhexamid on the acute contact toxicity of the insecticides thiamethoxam (neonicotinoid) and bifenthrin (pyrethroid) to the common eastern bumble bee, *Bombus impatiens*. They reported that certain SBI fungicides are particularly harmful to bumble-bee health when used together with insecticides, despite their low toxicity when applied in isolation. Lopez *et al.* (2017) report that the combined effect of three different pesticides (dimethoate, clothianidin and fluvalinate) and American foulbrood infection set off a synergistic impact and caused significantly higher mortality than caused by the stressors individually. The same authors also report significant immunocompromise caused by a drastic reduction of the total and differential haemocyte counts in co-exposed larvae.

**Figure 17. Expert-opinion analyses of the importance of direct drivers on pollinators in different regions**




*Notes*: These regions do not correspond to the FAO-recognized regions and are cited here as in the original publication (Dicks *et al.*, 2021). The dark blue denotes lack or no information in order to assess the status of the driver on pollinator populations within that region. There is a lack of information on GMOs across all regions and so their importance in terms of risk to pollinators cannot be assessed.

*Source*: Dicks, L.V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M. del C., Cunningham, S.A., Galetto, L. *et al.* 2016a. Ten policies for pollinators. *Science*, 354(6315): 975–976. https://doi.org/10.1126/science.aai9226

A major study that involved quantification of 24 habitat, land-use and pesticide usage variables across 284 sampling locations in the United States of America to examine reasons for range restrictions in several bumble-bee species (McArt *et al.*, 2017) reports that greater use of the fungicide chlorothalonil increased pathogen (*Nosema bombi*) prevalence in four declining species of bumble bee and may have contributed to their range restriction. Tosi and Nieh (2019) found evidence that the new systemic pesticide Flupyradifurone and the SBI fungicide propiconazole had lethal and sublethal synergistic effects on *Apis mellifera*.

The IPBES (2016) pollinator assessment did not assess the impact of multiple stressors on pollinators or compare and rank the relative importance of direct drivers – which may vary regionally, nationally or locally. Through an expert-solicitation method, Dicks *et al.* (2021) examined the variation of different direct drivers by region (Figure 17).

# Chapter 3. Status and trends of management practices affecting invertebrate pollinators

Management of pollinators includes practices and approaches for all pollinators, and the specific management of domesticated pollinators. Pollinator-friendly management practices, systems and processes have the potential to maintain rich and abundant wild-pollinator communities if sustained over time. These processes and systems include sustainable intensification, agroecology, organic farming and (IPM; below ecological intensification and agroecology will be discussed more in detail. Such approaches aim to increase long-term crop productivity by enhancing beneficial biodiversity, including pollinator diversity, and associated ecosystem services/nature's contributions to people, while minimizing the use of synthetic inputs and cropland expansion. Recent studies support a focus on ecological processes and on ecological intensification[8] as an important solution to pollinator declines that will also provide other benefits such as natural biocontrol, better soil function and sustained food security (Garratt *et al.*, 2017; Kovács-Hostyánszki *et al.*, 2017; Tamburini *et al.*, 2017; Kleijn *et al.*, 2019; Kremen, 2020; Chen *et al.*, 2021).

## 3.1 Ecological intensification

Ecological intensification aims to increase long-term crop productivity by enhancing biodiversity and associated nature's contribution to people, while minimizing the use of synthetic inputs and cropland expansion (Garibaldi *et al.*, 2019). For pollinators in particular, ecological intensification aims to increase pollinator diversity as a way of enhancing crop pollination and, consequently, the quality, quantity and resilience of crop yield. By definition, therefore, ecological intensification practices should benefit pollinators.

Ecological intensification describes a process rather than an endpoint and could be considered a component of efforts to meet more comprehensive objectives such as those of agroecology and sustainable intensification. Therefore, many practices that are consistent with the principles of ecological intensification are also discussed in the context of agroecology and other farming systems (Vanbergen *et al.*, 2020). These practices aim to promote the abundance and diversity of floral and nesting resources, including by restoring natural or semi-natural areas, enhancing crop and wild plant diversity within fields and establishing flower strips and hedgerows (Garibaldi *et al.*, 2014). These changes will also increase farmland heterogeneity, thus benefiting the sustainability of agriculture more generally. Ecological intensification practices also aim to reduce the direct factors of pollinator mortality, for example reducing the use of pesticides (Garibaldi *et al.*, 2019).

## 3.2 Agroecology and pollination

Understanding the impacts of farm management on an ecosystem service such as pollination demands a careful focus to identify the salient features of the ecosystem service and how the farming system impacts these, as well as how governance systems can enable positive outcomes.

Research has clearly indicated that wild pollinators are twice as effective as managed pollinators in producing seeds and fruit on key crops (Garibaldi *et al.*, 2013). The IPBES (2016) pollinators' assessment reports that more diversified farming systems that involve practices such as intercropping, polyculture, crop rotations, cover-cropping, fallowing, agroforestry, insectary strips and hedgerows, if sustained over time, have the potential to maintain rich communities of wild pollinators. It also points to the threats posed to pollinators by monoculture systems that are highly dependent on chemical inputs.

What remains lacking is a substantive treatment of how a diversity of wild pollinators can be built up and sustained over the long term in agroecosystems (Roubik and Gemmill-Herren, 2016). The least stable ecosystems, ecologically, are large agricultural monocultures. Biologically simplified farms larger than

[8] For the purposes of the present study, ecological intensification is taken to be a process rather than an end point. It provides one path towards higher crop yield that fits within the original sense of sustainable intensification. Ecological intensification emphasizes management to enhance ecological processes that support production, including biotic pest regulation, nutrient cycling and pollination; there is an explicit focus on conserving and using functional biodiversity. The result is a farm that is likely to meet the definition of a diversified farming system (Garibaldi *et al.*, 2019).

pollinator flight ranges create environments that are effectively isolated and have depauperate pollinator fauna. Research has shown that for farms with fields smaller than 2 hectares (the majority of smallholder farmers worldwide), a diverse suite of wild pollinators can close yield gaps in pollinator-dependent crops by a median of 24 percent (Garibaldi *et al.*, 2016). What is most salient from these findings is the key role of small field sizes, which provide benefits for both biodiversity and yield outcomes. It should be noted that such findings are also relevant for large farms that maintain diversity on-farm and through smaller field sizes.

A recent focus involving agroecology has been on "agroecological innovations", which FAO defines as those that "apply ecological principles – such as recycling, resource use efficiency, reducing external inputs, diversification, integration, soil health and synergies – for the design of farming systems that strengthen the interactions between plants, animals, humans and the environment for food security and nutrition" (FAO, 2018). There has also been a focus on whole agrifood systems (i.e. not just farming systems) and their ecological, economic and social dimensions (Gliessman, 2018).

The ten elements of agroecology (FAO, 2018) support ways to maintain diversity on-farm and in agricultural landscapes. Five of the elements address foundational practices and innovative approaches, and the remaining five focus on social contexts and governance. The relevance of each for pollinator-friendly practices is outlined below.

Agroecological elements relevant to promoting pollinator-friendly practices on-farm and across landscapes

- **Diversity**: Agroecological systems and practices stress high diversity, through such measures as intercropping or crop rotation, or maintenance of some patches within farmland in a semi-natural status, enhancing the provision of ecosystem services such as pollination and natural pest control. Considerable research has documented the contribution of diversified farming systems to pollination services, for example that increased crop diversity enhances pollinator abundance and richness (Guzman *et al.*, 2019).
- **Synergies**: Agroecological approaches emphasize farm design to promote synergies that make system transitions favourable in multiple respects (Vanbergen *et al.*, 2020). For example, hedgerows in Ghana have been designed both to lure pollinators to crops and to provide food security (Isaacs *et al.*, 2016). Similarly, cover crops have been shown to build soil health, suppress weeds and provide forage for pollinators in North America (Bryan *et al.*, 2021).
- **Efficiency**: Efficiency, when developed agroecologically through optimizing biological processes, is not a function of greater output per unit input but an emergent quality of an ecosystem that uses and generates its internal resources and consequently does not "leak" unused resources such as nutrients or pesticides into the environment, causing severe pollution. Application of pesticides, herbicides and even fertilizers can all have serious impacts on pollinators (Ramos *et al.*, 2018).
- **Resilience**: Resilience can be defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks" (Folke *et al.*, 2010). Agroecological practices aim to work with the biological complexity of agricultural systems to promote a diverse community of interacting organisms that allows the ecosystem to self-regulate in the face of challenges such as pest and disease outbreaks, thus mitigating the use of chemicals toxic to pollinators (Midega *et al.*, 2018).
- **Recycling**: Fostering recycling is central to agroecology because it increases efficiency by progressively replacing waste and pollution with biological processes that ensure the flow, use and cycling of nutrients. This can occur at multiple levels and be augmented within farms and landscapes by measures such as integrating livestock with crops. Recycling is often a central component of nutrient management; recent research has shown that optimal levels of pollination can compensate for the reduced levels of nitrogen applications that may be part of agroecological approaches (Tamburini *et al.*, 2017).

Agroecological elements relevant to creating the enabling environment for pollinator-friendly farming systems

The focus of agroecology on social contexts and governance aspects, while seemingly unrelated to pollinator conservation, are in fact integral to creating an enabling environment for pollinator-friendly farming systems, and thus to their uptake and success. Farmers do not manage single aspects of their farms in isolation from each other. Measures aimed at sustaining pollinators need to be embedded in overall food- and farming-system transitions away from high-input monoculture agriculture or resource-destructive forms of farming. The policies needed in order to facilitate such a transition are well documented in the 2019 UN Committee on Food Security High Level Panel of Experts report *Agroecology and other innovative approaches for sustainable agriculture and food systems that enhance food security and nutrition.* (HLPE, 2019). The report finds that conventional approaches such as sustainable intensification may be effective within selective domains but do not lead to the food-system transformations needed. As the report notes, building such a new global food system must be based on respecting human and social values, build on cultural traditions, and ensure participation, fairness and justice through responsible governance, among others of the agroecological elements listed in this section.

- **Human and social values**: In identifying levels for the transition to more just and equitable food systems, changes in perceptions and actions are needed. These changes should respect a range of values, including external costs and benefits, which are an important input into decision-making on sustainable food systems. Yet the externalities of agriculture- both positive and negative are rarely measured, either in economic terms or as human values. Research in both Kenya and the United States of America has shown that farms managed on ecological principles can support wider bee diversity – including rare species of bees – than adjacent wildlands, sustaining both farm yields and biodiversity (Gikungu, 2006; Winfree *et al.*, 2008).
- **Culture and food traditions**: Many cultures throughout the world have a long tradition of revering and respecting pollinators (Roy *et al.*, 2016). Agroecology plays an important role in reconnecting tradition and modern food habits.
- **Responsible governance**: Agroecology recognizes the importance of transparent, accountable and equitable governance of natural and human systems at all scales, which facilitates the transition process and promotes the economic efficiency and political stability required to achieve the sustainable development embodied in the targets of the Sustainable Development Goals.
- **Co-creation of knowledge**: Rather than offering fixed prescriptions, agroecological systems depend upon the context-specific knowledge of farmers and land managers. Promoting wild pollinators in agroecosystems begins with farmers' understanding of the pollination needs of their crops and the adaptive management practices needed to sustain healthy pollinator populations. Education in the form of farmer field schools and peer-to-peer sharing hasbeen shown to be effective in designing pollinator-friendly practices.
- **Circular and solidarity economies**: The concept of circular economy goes beyond the production and consumption of goods and services: it seeks fair solutions based on local needs, resources and capacities, creating equal and sustainable markets. Farming systems have strong dependencies on the forms of their markets; while much of the economic focus of ecosystem services stresses replacing purchased inputs with regenerative ecosystem services, a key part of the enabling environment for pollinator-friendly practices is building markets that favour agroecological outputs (Wach, 2021).

The inherent complexity of farming systems based on agroecology can be daunting to decision-makers, particularly as it is stressed that the elements of agroecology must work together, not implemented in isolation.  Taken as an analytical framework, however, the ten elements of agroecology as briefly outlined above can be used to support the design of differentiated paths for agriculture and food system transformation, with multiple possible entry points (Barrios *et al.*, 2020). Each of these pathways can contribute to creating and sustaining pollinator-friendly agricultural landscapes.

Many broader conservation efforts, for example the maintenance of habitat diversity or increasing habitat richness, have a positive effect on a wide range of organisms, including invertebrate pollinators and plants but these co-benefits have not been well researched. For example, in the case of increased habitat complexity providing benefits for both pollinators and natural enemies, Shackelford *et al.* (2013) found that landscape complexity had positive effects on both pollinators and natural enemies (pest control) resulting in less vulnerability of these ecosystem services. There has also been little research examining whether targeted conservation actions for pollinator habitat have enhanced overall biodiversity and ecosystem services.

## 3.3 Management, breeding and conservation of honey-bee (*Apis mellifera*) subspecies

The diversity of honey-bee species and subspecies is important for the continued delivery of pollination services. Conserving and sustainably using locally adapted genetic resources is essential for successful and sustainable breeding programmes. Honey-bee genetic resources are considered to be animal genetic resources for food and agriculture that can be used for breeding and whose diversity needs to be conserved, and as such data on them are documented in the Domestic Animal Diversity Information System (DAD-IS)[9] (see Section 4.3.3 for more information).

### 3.2.1. Breeding challenges

Breeding programmes should not be confused with queen-rearing activities. A breeding programme is defined as "a set of systematically planned and implemented activities aimed at the sustained genetic improvement of a honey bee population (Brascamp, 2014; Tiesler *et al.*, 2016)" (Uzunov *et al.*, 2017). Breeding programmes provide the opportunity to conserve genetically attractive local subspecies (Plate *et al.*, 2019). Improving breeding programmes involves making molecular testing accessible and available to bee breeders (Čápek and Chlebo, 2016). By contrast, queen rearing to produce new queens to requeen colonies has the following objectives: preventing swarming, maintaining a healthy level of brood and honey within the hive, modifying genetic characteristics and/or starting new colonies (Laidlaw and Page, 1997; Ruttner, 1983).

Many European native subspecies may be hybridized or replaced by, for example, *Apis mellifera carnica* or *Apis mellifera ligustica* (De la Rúa *et al.*, 2009; Cauia *et al.*, 2010; Hatjina 2012; Uzunov *et al.*, 2018). *Apis cerana* is facing similar threats of replacement and hybridization in Asia (Yang, 2005, Peck and Seeley, 2018). At times, introgression[10] of genes from foreign subspecies is deliberately carried out by beekeepers. For example, beekeepers in Europe are substituting *Apis mellifera mellifera* with *Apis mellifera carnica* (Meixner *et al.*, 2010) which can threaten the autochthonous (native) subspecies with introgression from the foreign subspecies. Introgressive human-mediated hybridization has also been documented for *Tetragonula* (Francisco *et al.*, 2014; Chapman *et al.*, 2018) and *Melipona* species (Nascimento *et al.*, 2000).

Soland-Reckeweg *et al.* (2008) examined levels of hybridization in sympatric[11] and allopatric[12] *Apis mellifera mellifera* (native) and *Apis mellifera carnica* (introduced) populations and discovered that "for *Apis mellifera carnica*, hybrids were detected in 75% of the pure breeding populations in western and in 80% of the breeding populations in eastern Switzerland. Similarly, in 83.3% of the *Apis mellifera mellifera* pure breeding populations, hybrids were also detected". The results demonstrate that within the two zones (sympatric and allopatric) the subspecies are "still highly differentiated" but that effective conservation measures are necessary to regulate gene flow. The extent to which hybridization leads to introgression is not clear (Nascimento *et al.*, 2000).

Successful breeding normally occurs under effective controlled mating processes. Unfortunately, controlled mating processes are relatively difficult to attain with queen honey bees (Cobey, 2007; Plate *et al.*, 2019). Honey bees have a complex reproductive biology. Queen honey bees can have one or more mating flights where queens have been found to mate with up to 45 drones, which provides the diversity of genetic sources (Moritz *et al.*, 1996; Kraus *et al.*, 2005) and makes controlled mating difficult. Successful breeding also depends on drone health and reproductive capacity (Rangel and Fisher, 2019).

There are three types of honey-bee breeding programmes: commercial, conservation and research. The description provided here is taken from Uzunov *et al.* (2017):

- "**Commercial**, aimed to improve the overall performance of the honey bees from the population of interest, based upon the assessment of various traits. Occasionally, the number of traits is limited to 3 or 4. However, the main drive and objective of these commercial breeding programs is improvement in commercially important traits (more honey, less defensive bees, reduced swarming tendency, etc.). This type of selection is most common and considered by us as the most sustainable.
- **Conservation**, aimed at the maintenance of endangered honey bee populations. The ultimate goal is maintenance or enlargement of the population. Genetic improvement of such populations is a useful tool in the

[9] http://www.fao.org/dad-is/en/
[10] The introduction of new gene(s) into a population by crossing between two populations, followed by repeated backcrossing to that population while retaining the new gene(s) (FAO, 1999).

[11] Occurring in overlapping geographical areas.
[12] Occurring in non-overlapping geographical areas.

**Box 3. SMARTBEES conservation programme**

Funded by the European Commission, the Sustainable Management of Resilient Bee Populations (SMARTBEES) conservation programme[*] is coordinated by the Institute for Bee Research, Hohen Neuendorf e.V. (Germany) and aims to prevent honey-bee colony losses caused by pests and diseases and to conserve native European bees. The SMARTBEES programme supports local breeding activities in all European honey-bee subspecies, with a special focus on the populations most at risk. Currently 16 partner organizations from 11 countries in the European region participate in the SMARTBEES programme. SMARTBEES has conducted seminars and training events in Norway, Croatia, France, Greece, Lithuania, Malta, Norway, Poland, Portugal, Romania and elsewhere. It has also created a new tool for subspecies conservation and breeding from 4 000+ single nucleotide polymorphisms (SNPs) (Momeni *et al.*, 2021).

*Sources*: Momeni, J., Parejo, M., Nielsen, R.O., Langa, J., Montes, I., Papoutsis, L., Farajzadeh, L. *et al.* 2021. Authoritative subspecies diagnosis tool for European honey bees based on ancestry informative SNPs. *BMC Genomics*, 22(1): 101. https://doi.org/10.1186/s12864-021-07379-7

[*] https://www.smartbees-fp7.eu/

context of "conservation by utilization", as conservation by utilization is considered a preferred mechanism to conserve subspecies or populations. Along with commonly recognized traits, relevant on the regional or local scale, morphological characters and molecular markers are frequently the basis for decision-making and selection, the latter two being used to ensure that the population is not mixed with other subspecies.

- **Research** breeding programs can be initiated for studying certain traits (effects of the genes, identification of markers, etc.) of scientific interest as well as analyzing the effects of hybridization or inbreeding, assessing the adaptive ability of populations, resistance to diseases, genotype by environment interactions, etc. Generally, these breeding programs are short-term and under the responsibility of research institutes or other academic institutions."

There are several other tools and programmes that focus on bee breeding, such as SMARTBEES (see Box 3) and the BeeBreed website. BeeBreed.eu[13] is an online tool that provides access to breeding values of queens, breeding and performance data (accessible only to members), additional information (manual for breeders, general information about genetic evaluation, etc.) and contact information on breeding administrators. The official breeding value estimations in BeeBreed.eu can be used to characterize breeding progress and inbreeding.

The status and trends of bee-breeding programmes were discussed in *The State of the World's Biodiversity for Food and Agriculture* (FAO, 2019), which indicated that there were estimated to be approximately 100 such programmes worldwide, most of which were commercial enterprises.

### 3.2.2. Conservation of genetic information

Germplasm conservation (both *in situ* and *ex situ* conservation for subspecies and ecotypes); *ex situ* germplasm cryopreservation is described as "the storage of biological material at ultralow temperature, usually that of liquid nitrogen (-196 °C), is the only technique currently available to ensure the safe and cost-efficient long-term conservation of these different types of germplasm" (Engelmann, 2004).

Germplasm cryopreservation is not a widely known or used conservation technique for insect diseases – it is normally used for insect pathogens or parasitic protozoans as biocontrol agents (Leopold, 1991; Leopold and Rinehart, 2010; Campion *et al* 2021). Despite advances in the field of cryopreservation of honey-bee drone semen, fertility levels remain low (Wegener *et al.*, 2014) and further complexity arises with the mating biology of queen honey bees (highly polyandrous) storing viable semen from several drones in her spermatheca for several years (Baer *et al.*, 2009).

[13] https://www2.hu-berlin.de/beebreed/ZWS

The first successful cryopreservation techniques for bumble bees (*Bombus impatiens*) were recently reported and involve the use of a technique that has been effective in honey bees (Campion *et al*., 2021). However, the technique needs improvement in terms of "spermatozoa [viability and] motility and genomic fragmentation" (Campion *et al*., 2021).

In February 2019, the German Federal Ministry of Food and Agriculture entrusted two Bee Research Institutes with the task of establishing a national gene reserve for the honey bee in Germany. Viert *et al*., 2021 describes the status of this gene bank for honey bees in the context of Europe. Elsewhere in Europe there is a limited collection of honey-bee genetic resources in the national gene bank of Slovenia, and initiatives to develop public collections of honey-bee germplasm are also underway in Norway and Spain (Viert *et al*., 2021). The German cryobank of honey bee genetic resources is considered the first gene bank in Europe as part of the German Gene Bank for Agricultural Livestock with the main objective as conservation. The gene bank will house the Carnica and Mellifera breeding lines held in Germany (Viert *et al*., 2021). It currently stores drone semen, tissue samples and whole-body preparations from drones and other bees. Information on these samples will be entered into the European Farm Animal Biodiversity Information System (EFABIS)[14] – which is the data portal for European information on animal genetic resources and is used by European national coordinators for animal genetic resources – all of this information contributes to DAD-IS (see Section 4.3.3 for more information).

This section describes a variety of *in situ* and *ex situ* conservation strategies that can be used to safeguard honey-bee subspecies and genetic diversity and meet the demands of beekeepers, including genetic assessment of populations using diagnostic tools (Momeni *et al*., 2021), gamete cryopreservation (cryopreservation of drone semen) (Wegener *et al*., 2014), effective breeding strategies for genetic improvement of local subspecies (Büchler *et al*., 2010, 2013; Uzunov *et al*., 2015) and establishment of a common repository for characterization data.

Few honey-bee conservation programmes have been established to date, and most of those that do exist are in Europe – which may be a result of the region's high honey-bee subspecies diversity being endemic to Europe. There is a need for a stronger networking and collaboration among institutions and researchers and for common approaches to the collection, cataloguing, storage and use of genetic material. A few initiatives are in place (see Box 3) or are being set up, such as a working group on honey-bee gene banking led by the International Federation of Beekeepers' Associations (Apimondia); however, effective conservation will require such efforts to be strengthened and better coordinated for (K. Bienefeld pers. comm). The next steps in evaluating the status and trends of subspecies will involve a more rigorous census of past and existing *in situ* and *ex situ* conservation programmes and their achievements. Breeding programmes are a key long-term means of addressing threats to local honey-bee populations (Niño and Jasper, 2015).

### 3.2.3. *Ex situ* conservation

The literature on *ex situ* conservation programmes for invertebrate pollinators is relatively scant, especially in the case of wild pollinators; the little information there is relates mainly to honey bees (*Apis* species) and bumble bees (*Bombus* species) (IPBES, 2016).

Examples of *ex situ* conservation activities include those of the National Bank of Biological Material,[15] which was established by the National Research Institute of Animal Production in Poland (Animal Genetic Resources in Poland, 2013) and has a cryopreservation and storage unit for local honey-bee semen (Trzcińska and Kralka-Tabak, 2021). More information on cryoconservation can be found also in Section 3.2.1.

In Brazil, the project Conservação de Recursos Genéticos de Insetos Polinizadores (Conservation of Genetic Resources of Pollinating Insects)[16] 2016–2020 focused on the conservation of bee genetic resources in several regions within the country (Northern, Northeastern and Southeastern). The project involved 41 species of stingless bees and four species of solitary bees. It was reportedly going to implement *in situ* and *ex situ* conservation actions (Santilli, 2013), but more information is not currently available.

[14] http://www.fao.org/dad-is/regional-national-nodes/efabis/en/

[15] https://kbmb.izoo.krakow.pl/en

[16] https://www.embrapa.br/busca-de-projetos/-/projeto/210682/conservacao-de-recursos-geneticos-de-insetos-polinizadores

# Chapter 4. Policies, instruments and initiatives for the sustainable use and conservation of pollinators

This chapter provides an overview of existing initiatives, policies and instruments related to pollinators and pollination at global, regional, national and subnational levels. Many of these initiatives, policies and instruments are underpinned by several other types of activities and tools such as guidance documents, policy reports, primary research and networks. This chapter is based on a literature review and data analyses and includes the results of a questionnaire sent out to all FAO member countries and interested stakeholders and of a qualitative data analysis of national biodiversity strategies and action plans (NBSAPs).

## 4.1 International policies and instruments

### 4.1.1. Convention on Biological Diversityand the International Initiative for the Conservation and Sustainable Use of Pollinators

Work on pollinators and pollination under the CBD dates back to the third Conference of the Parties to CBD in 1996, when decision III/11 (Conservation and sustainable use of agricultural biological diversity) acknowledged the importance of pollinators for crop production and yields and highlighted pollinators as the topic of one of two initial issues for case studies (CBD, 1998).

In 1999, a report referred to as the São Paulo Declaration on Pollinators prepared by the Brazilian Ministry of the Environment in collaboration with pollination experts (Dias *et al.*, 1999) was submitted at the fifth meeting of the Subsidiary Body for Scientific, Technical and Technological Advice (SBSTTA) to the CBD. This report made recommendations for the implementation of an international initiative on the conservation and sustainable use of pollinators in agriculture. This report and the subsequent work helped inform the establishment of the International Initiative for the Conservation and Sustainable Use of Pollinators as a cross-cutting initiative within the CBD's programme of work on agricultural biodiversity (CBD, 2000) to promote coordinated action worldwide. Subsequently, by decision VI/5 (2002), the CBD adopted a plan of action. FAO has been leading and facilitating the implementation of both the first and second International Pollinator Initiative Plan of Action (2000–2015 and 2018–2030).

**The International Pollinator Initiative and the first Plan of Action for its implementation**

In 2002, knowledge gaps on pollinators and pollination were far larger than they are today, and the objectives of the first Plan of Action emphasized four foci: (i) monitoring pollinator decline, its causes and its impact on pollination services; (ii) addressing the lack of taxonomic information on pollinators; (iii) assessing the economic value of pollination and the economic impact of the decline of pollination services; and (iv) promoting the conservation, restoration and sustainable use of pollinator diversity in agriculture and related ecosystems. At the end of the first Plan of Action, the monitoring of pollinators had improved, and more taxonomic information was available. However, there were still gaps in knowledge and in terms of economic valuation, and continuous work was needed in the areas of conservation, restoration and sustainable use.

FAO, in its work facilitating and implementing the International Pollinator Initiative, has developed in the context of the Plan of Action 2000–2015 methods and protocols for monitoring pollinators and pollination (see Annex I) in the following countries: Argentina, Brazil, China, Colombia, France, Ghana, India, Indonesia, Kenya, Nepal, Norway, Pakistan, South Africa and Zimbabwe. Further work has been done regarding risk assessment methods of pesticides for different bee taxa in Brazil, Kenya and the Kingdom of the Netherlands. The development of many regional and national pollinator initiatives was also supported (see Section 4.5.1).

The International Pollinator Initiative has prompted many pollinator-related activities worldwide, including the approval by IPBES Member States of plans to undertake the first global assessment of pollinators, pollination and food production (2014 to 2016), which was also IPBES's first knowledge product as a new intergovernmental body.

**International Pollinator Initiative and the Plan of Action 2018–2030**

In 2016, the summary for policymakers of the IPBES pollinator assessment was approved and the chapters were accepted (see Section 4.3.5). At its thirteenth meeting, the Conference of the Parties to the CBD formally endorsed the key messages of the IPBES assessment and recognized "the contribution of pollinators to the Sustainable Development Goals, especially Goals 2, 3, 8 and 15" (decision XIII/15) (CBD, 2016c). Under the same decision, the Conference of the Parties encouraged "Parties, other Governments, relevant United Nations and other organizations, as well as multilateral environment agreements, and stakeholders to use, as appropriate, the Assessment, in particular the examples of responses outlined in table SPM.1 [see Annex II], to help guide their efforts to improve conservation and management of pollinators, address drivers of pollinator declines, and work towards sustainable food production systems and agriculture."

As noted above, the Conference of the Parties, at its fourteenth meeting, adopted Plan of Action 2018–2030 and emphasized that it was intended to "help Parties, other Governments, indigenous peoples and local communities, relevant organizations and initiatives to implement decision XIII/15" (CBD, 2018). The four objectives of the Plan of Action 2018–2030 are to support countries and other stakeholders:

a) "In implementing coherent and comprehensive policies for the conservation and sustainable use of pollinators at the local, subnational, national, regional and global levels, and promoting their integration into sectoral and cross-sectoral plans, programmes and strategies;

b) In reinforcing and implementing management practices that maintain healthy pollinator communities, and enable farmers, beekeepers, foresters, land managers and urban communities to harness the benefits of pollination for their productivity and livelihoods;

c) In promoting education and awareness in the public and private sectors of the multiple values of pollinators and their habitats, in improving the tools for decision-making, and in providing practical actions to reduce and prevent pollinator decline;

d) In monitoring and assessing the status and trends of pollinators, pollination and their habitats in all regions and to address gaps in knowledge, including by fostering relevant research" (CBD, 2018).

Through the same decision, FAO was again requested to facilitate the implementation of the International Pollinator Initiative through guidance and technical advice to countries and to support decision-making processes on pollination, including on the use of chemicals in agriculture, protection programmes for native pollinators in natural ecosystems, promotion of biodiverse production systems, crop rotation, monitoring of native pollinators and environmental education (CBD, 2018).

### 4.1.2. Access and benefit-sharing

The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (Nagoya Protocol) "is an international agreement which aims at sharing the benefits arising from the utilization of genetic resources in a fair and equitable way."[17] This agreement, which entered into force in October 2014, provides a legal framework for ensuring the fair and equitable sharing of benefits arising out of the utilization of genetic resources, one of the objectives of the CBD.

Literature regarding access and benefit-sharing and bee genetic resources is scant. Viert *et al.* (2021) report that German beekeepers who donate genetic material to the cryobank mentioned in Section 3.2.1 receive the results of the analyses run on the material donated as compensation and that donors of genetic material (queen or drone brood) from outside Germany are paid (monetarily compensated). In order to comply with the Nagoya Protocol, the biobank had confirmed with the national focal points to the CBD of the countries from which it had received genetic resources (with the exception of Slovenia, which is not a party to the Nagoya Protocol) that the material received was freely accessible (Viert *et al.*, 2021).

### 4.1.3. Promote Pollinators

The Coalition of the Willing on Pollinators (now referred to as Promote Pollinators)[18] was formed after the approval and publication of the IPBES

[17] https://www.cbd.int/abs
[18] https://promotepollinators.org

**Box 4. Case study: bees and access and benefit-sharing in India**

India's Biological Diversity Act passed in 2002 has a chapter dedicated to the regulation of access to biological diversity. This states:

Certain persons not to undertake biodiversity related activities without approval of National Biodiversity Authority (1) No person referred to in sub-section (2) shall, without previous approval of the National Biodiversity Authority, obtain any biological resource occurring in India or knowledge associated thereto for research or for commercial utilisation or for bio-survey and bio-utilisation.

The definition of "commercial utilisation" explicitly exempts beekeeping:

(f) "commercial utilisation" means end uses of biological resources for commercial utilisation such as drugs, industrial enzymes, food flavours, fragrance, cosmetics, emulsifiers, oleoresins, colours, extracts and genes used for improving crops and livestock through genetic intervention, but does not include conventional breeding or traditional practices in use in any agriculture, horticulture, poultry, dairy farming, animal husbandry or bee keeping;

The provision above implies that "foreign and non-resident Indian nationals are exempt from the ABS [access and benefit-sharing] requirements for activities excluded from the definition of 'commercial utilisation', including activities of conventional breeding or traditional practices in use in the specified agricultural field" (Nijar, 2011). Within India, three authorities are responsible for the implementation of the act: The National Biodiversity Authority, the State Biodiversity Boards and the Biodiversity Management Committees at the local level (Humphries *et al.*, 2021).

*Sources*: Humphries, F., Benzie, J.A.H., Lawson, C. & Morrison, C. 2021. A review of access and benefit-sharing measures and literature in key aquaculture-producing countries. *Reviews in Aquaculture*, 13(3): 1531–1548. https://doi.org/10.1111/raq.12532; Nijar, G.S. 2011. Food security and access and benefit sharing laws relating to genetic resources: promoting synergies in national and international governance. *International Environmental Agreements: Politics, Law and Economics*, 11(2): 99–116. https://doi.org/10.1007/s10784-010-9131-9

pollination report. During the thirteenth COP to the CBD, which was held in Cancun, Mexico, in 2016, 14 countries (Austria, Belgium, Denmark, Finland, France, Germany, Luxembourg, Peru, Slovakia, Slovenia, Spain, the Kingdom of the Netherlands, the United Kingdom and Uruguay) signed a declaration containing a general commitment to protect pollinators. As of August 2021, 30 countries were members of Promote Pollinators.

## 4.2 Policies and instruments to reduce threats to pollinators

The CBD, through decision 14/6 on the conservation and sustainable use of pollinators, explicitly requested that these recommendations from decision 14/6 be brought to the attention of the following bodies:

- Commission on Genetic Resources for Food and Agriculture;
- FAO and its Committee on Forestry;
- FAO and its Committee on Agriculture;
- FAO and its Committee on World Food Security
- International Plant Protection Convention;
- International Treaty on Plant Genetic Resources for Food and Agriculture;
- Basel Convention;
- Rotterdam Convention; and
- Stockholm Convention.

The following (non-exhaustive) list of instruments and entities that support objective A1.2 ("Implement effective pesticide regulation") of the International Pollinators Initiative's Plan of Action 2018–2030 are described below: the Stockholm Convention on Persistent Organic Pollutants; the Rotterdam Convention; and the International Code of Conduct on Pesticide Management. Not all instruments and entities that contribute to reducing direct threats to pollinators can be discussed within this study. It is recognized that addressing other direct drivers affecting pollinators is as important as, if not more important than, addressing pesticide regulation. Key aspects of managing risks associated with pesticides include reducing or stopping pesticide use, enhancing and promoting appropriate pesticide risk assessment procedures, developing best practices, guidelines and pesticide risk reduction strategies, and developing or improving monitoring, surveillance and registration of pesticides.

### 4.2.1. Instruments that aim to implement effective pesticide regulation

#### Stockholm Convention

The Stockholm Convention on Persistent Organic Pollutants (UNEP, 2019) is a global treaty that was adopted in May 2001 and entered into force in 2004. The overarching objective of the Convention, as set out in Article 1, "is to protect human health and the environment from persistent organic pollutants." There have been several amendments to the original text, the latest in 2019. The revised text and annexes do not make explicit reference to invertebrate pollinators, pollinators in general or bees.

Recognizing that use of pesticides is increasing and has been demonstrated to be harmful to invertebrate pollinators and other beneficial insects, (namely neonicotinoids), Drivdal and van der Sluijs (2021) proposed that the Stockholm Convention phase these pesticides out, as they have done with other pesticides. They further recommend that neonicotinoids be included in the Conventions' Category A (Elimination). The Convention states that "Parties must take measures to eliminate the production and use of the chemicals listed under Annex A."

#### Rotterdam Convention

The Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade[19] is a global treaty that was adopted in September 1998 and entered into force in 2004. The objectives of the Convention are:

- "To promote shared responsibility and cooperative efforts among Parties in the international trade of certain hazardous chemicals in order to protect human health and the environment from potential harm;
- to contribute to the environmentally sound use of those hazardous chemicals, by facilitating information exchange about their characteristics, by providing for a national decision-making process on their import and export and by disseminating these decisions to Parties."

#### International Code of Conduct on Pesticide Management

The International Code of Conduct on Pesticide Management was approved in 1985 and is now in its fourth version (FAO and WHO, 2014). The objectives of the code are to "establish voluntary standards of conduct for all public and private entities engaged in or associated with the management of pesticides, particularly where there is inadequate or no national legislation to regulate pesticides."

Several subsidiary guidelines to the code have been produced, including the Guidelines on Highly Hazardous Pesticides, published in 2016 (FAO and WHO, 2016). Their overall purpose is to support regulators at all levels to address highly hazardous pesticides.

### 4.2.2. Organizations/instruments that improve animal health/reduce risk of disease transmission

This section discusses the World Organisation for Animal Health (WOAH) formerly known as the Office International des Epizooties (OIE)[20] and the European Food Safety Authority (EFSA).[21] It is recognized that these are not the only organizations or instruments that improve animal health and prevent/reduce disease transmission – they are presented as examples.

#### World Organisation for Animal Health

Established in 1924, the WOAH is "the World Trade Organization (WTO) reference organization for standards relating to animal health and zoonoses."[22] Its publications *Terrestrial Animal Health Code, Aquatic Animal Health Code, Manual of Diagnostic Tests and Vaccines for Terrestrial Animals and Manual of Diagnostic Tests for Aquatic Animals*

[19] https://treaties.un.org/pages/ViewDetails.aspx?src=TREATY&mtdsg_no=XXVII-14&chapter=27

[20] https://www.woah.org/en/home

[21] https://www.efsa.europa.eu/en

[22] https://www.woah.org/en/what-we-do/standards/#:~:text=The%20World%20Organisation%20for%20Animal,recent%20scientific%20and%20technical%20information

are the principal reference documents for WTO members in this field.

The commitment of WOAH to the issue of bee health was apparent in 1947, when it adopted its first resolution on bees, and since then it has emphasized the importance of reducing bee mortality and diseases (Vallat, 2014). WOAH has been doing "substantive work to provide veterinary services around the world with consistent, science-based recommendations on bee diseases and precautions for avoiding transboundary spread" (Vallat, 2014). Important honey-bee diseases are included in the *Terrestrial Animal Health Code* (Section 9 Apidae) and the *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals* (Section 3.2 Apinae).

Bee diseases have become globalized mainly because of failure to control cross-border trade in breeding stock, genetic material and agricultural products. WOAH lists six main pests, parasites and bacteria causing bee mortality: *Acarapis woodi* (tracheal mites), *Paenibacillus larvae* (American foulbrood), *Melissococcus plutonius* (European foulbrood), *Aethina tumida* (small hive beetle), *Tropilaelaps species* (ectoparasite) and *Varroa species* (ectoparasite). *Varroa destructor* is described as "the most serious worldwide pest of the western honeybee *Apis mellifera*" (Spivak, 1996; 1999). See Box 1 and Section 2.3 for more information on *Varroa destructor.*

WOAH's work on bee health involves collaboration with many centres and organizations. For example, it has designated the International Center for Insect Physiology and Ecology as its Collaborating Centre for Bee Health in Africa.[23] The Istituto Zooprofilattico Sperimentale del Lazio e della Toscana has been designated as the OIE Collaborating Centre for Good Beekeeping Management Practices and Biosecurity Measures in the Apiculture Sector.[24]

**European Food Safety Authority**

EFSA focuses on supporting and maintaining healthy bee stocks under its mandate to improve food safety and animal health in the EU. EFSA's institutional infrastructure includes many scientific panels and units (pesticide peer review unit, pesticides residues unit, GMO panel, etc.).[25] The following areas are foci for EFSA: pesticides, animal health and welfare and plant health, genetically modified organisms (GMOs), data collection and scientific assessment.

Recognizing the importance of multiple stressors (see Section 2.5), EFSA launched the MUST-B project. A "scientific opinion" on this topic prepared by EFSA for the European Parliament was published in 2021 (EFSA Scientific Committee *et al*., 2021).

## 4.3 International or regional organizations and initiatives working on pollinator monitoring

Monitoring of the status of species and subspecies of honey bees and other pollinators and information tools is essential for policy development. Organizations at various levels are involved in pollinator monitoring.

### 4.3.1. International Union for the Conservation of Nature

The International Union for Conservation of Nature (IUCN) has developed a Red List process in order to evaluate the status of a species and its extinction risk/threat category. Since its establishment over 50 years ago, the IUCN Red List has published the most comprehensive database of species conservation status and species extinction risk assessments based on quantitative criteria and threat categories (Mace *et al*., 2008; Hochkirch *et al*., 2021). Coverage of insect pollinators in the global Red List is limited. Red List assessments of risk status at regional scale have been completed for European bees (Nieto *et al*., 2014) and butterflies (Van Swaay *et al*., 2010). Based on these sources, the IPBES (2016) pollinators assessment concludes that 9 percent of bee and butterfly species in Europe were threatened at the time the Red Lists were prepared, and that the populations of 37 percent and 31 percent of the region's bee and butterfly species, respectively, were declining (excluding species for which there were data deficiencies – almost 60 percent in the case of bees). Where national Red List assessments had been done, they often indicated that over 40 percent of bee species may be threatened. As well as being sources on information on risk status and population trends, Red List assessments also cover species distributions and ecological requirements (Hoffmann *et al*., 2008). In combination with other datasets, they could be a powerful assessment tools for conservation and global policy (Rodríguez 2008; Maes *et al*., 2015). There are methodological limitations to the Red List process (Fox *et al*., 2019). However, Red Lists are considered an appropriate starting point or proxy for

[23] http://www.icipe.org/news/icipe-designated-oie-collaborating-centre-bee-health-africa
[24] https://www.izs.it/IZS/OIE_Collaborating_Centre_for_Good_Beekeeping_Management_Practices_and_Biosecurity_Measures_in_the_Apiculture_Sector
[25] https://www.efsa.europa.eu/en/topics/insect-pollinator-health

**Box 5. Recent European Food Safety Authority (EFSA) action on honey bees**

In order to improve on risk assessment:

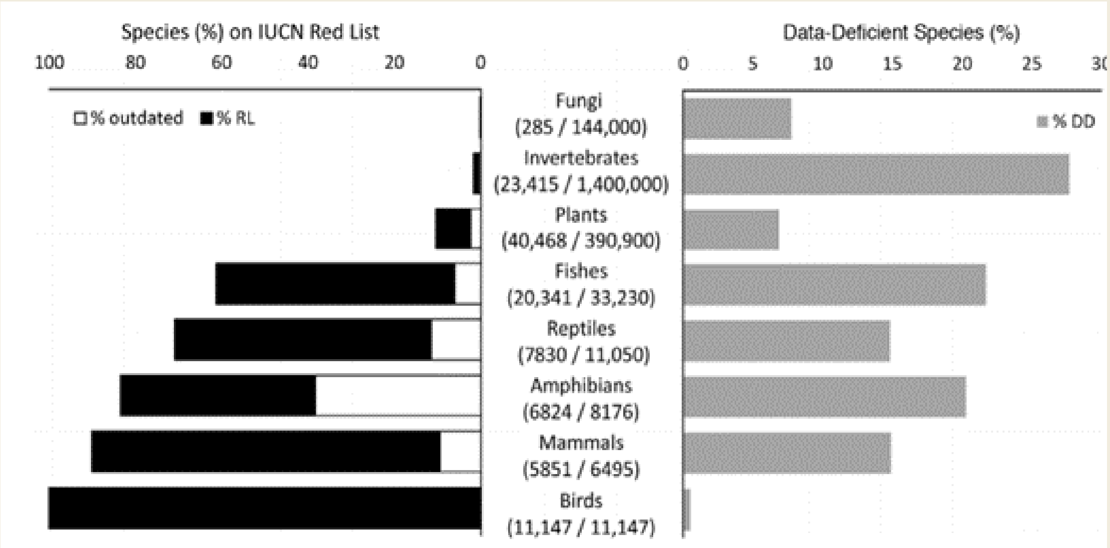
May 2021: A new scientific opinion, requested by the European Parliament's Committee for the Environment, Public Health and Food Safety (ENVI), sets out an integrated, holistic framework for assessing the combined effects of multiple stressors on honey bees (MUST-B).

March 2021: As part of its revision of the guidance on bees and pesticides, EFSA's working group publishes a method for defining specific protection goals (SPGs) for honey bees on the basis of the background variability of colony sizes. EFSA developed the document in response to a request from risk managers to provide scientific background to support them in their decision-making process about what needs to be protected and to what extent.

In December 2020, EFSA published a document to support risk managers in setting specific protection goals (SPGs) for bees. The document – part of the revision of guidance on bees and pesticides – lays out an approach for deriving a threshold of acceptable effects on colony size based on background variability. It follows a first supporting document published in June which offered risk managers a choice of four approaches to reviewing the SPGs.

*Source*: https://www.efsa.europa.eu/en/topics/topic/bee-health; https://www.efsa.europa.eu/en/events/advancing-environmental-risk-assessment-bees-and-other-insect-pollinators

**Figure 18. Species assessed for the IUCN Red List of Threatened Species**




*Note*: Left: the percentage of species assessed for the IUCN Red List of Threatened Species, with the white bars indicating outdated assessments (over ten years old). Middle: numerical figures for the percentage of species assessed for Red List assessments. Right: the percentage of species assessments with data deficiencies based on an estimated number of described (known) species.

*Source*: Hochkirch, A., Samways, M.J., Gerlach, J., Böhm, M., Williams, P., Cardoso, P., Cumberlidge, N. *et al.* 2021. A strategy for the next decade to address data deficiency in neglected biodiversity. *Conservation Biology*, 35(2): 502–509.

**Table 2. Number and proportions of countries with national systems for monitoring pollinator populations**

| Status of national systems | Honey bees | | Other pollinators | |
|---|---|---|---|---|
| | Number | Percent | Number | Percent |
| Existent | 78[a] | 72 | 44[b] | 41 |
| Non-existent | 24 | 22 | 55 | 51 |
| Unknown | 6 | 6 | 9 | 8 |

[a] In nine of these countries only some species of honey bees are regularly monitored.
[b] Refers to the existence of monitoring systems for at least one species of pollinator other than Apis honey bees.

*Source:* Halvorson, K., Baumung, R., Leroy, G., Chen, C. & Boettcher, P. 2021. Protection of honeybees and other pollinators: One global study. *Apidologie*, 52(3): 535–547. https://doi.org/10.1007/s13592-021-00841-1

status and trends of insect populations, and IUCN continues to do important work on the development of Red Lists for insects.

### 4.3.2. Global Biodiversity Information Facility

The Global Biodiversity Information Facility (GBIF) was formally established in 2001. GBIF is the largest global biodiversity network and data portal, housing over 1.6 billion species-occurrence records (Heberling *et al.*, 2021; Shulman *et al.*, 2021). All of the biodiversity data stored by GBIF are free and open access. Orr *et al.* (2021) analysed over 1.5 million original GBIF records in conjunction with several other bee databases and national bee checklists to reveal important patterns in global bee-species richness. As with the IUCN Red List assessments, there are geographical, sampling effort, habitat type, temporal and taxonomic biases in the GBIF dataset for insects (Rocha-Ortega *et al.*, 2021) as well as scattered insect records, record errors, duplicate records, incorrect species identifications, incompatible data formats, etc. (Orr *et al.*, 2021). Estimates of pollinator populations and their trends are lacking for most countries (Bartomeus *et al.*, 2019), and a knowledge gap is clearly demonstrated by the various above-mentioned biases, which highlight the need for more standardized data collection and information on lesser known, more difficult taxonomic groups in understudied regions.

### 4.3.3. Domestic Animal Diversity Information System

DAD-IS[26] is a global information system developed and maintained by FAO in which countries record information on their livestock breeds, including on the status and trends of their populations. These data can be freely accessed via the DAD-IS website, which provides users with various tools[27] for visualizing summarized data. They are also used to prepare reports on the global status and trends of animal genetic resources (e.g. FAO, 2022) and to calculate indicators of progress towards the Sustainable Development Goal Targets related to animal genetic resources (Targets 2.5.1 and 2.5.2). In 2017, the Commission requested FAO to consider including data on honey bees in DAD-IS (FAO, 2017), and this request was subsequently implemented (FAO, 2021).

Countries are encouraged to regularly report on honey-bee subspecies (and other bee species, including those in the genus *Melipona*) and hive numbers. They are also encouraged to work with FAO to upload best practices, guides and other publications to DAD-IS .

A survey on pollinators and their management launched through DAD-IS in 2017 received responses from almost 300 respondents from 108 countries (Halvorson *et al.*, 2021). The responses indicated that *Apis mellifera* was present in nearly all the 108 countries and that its populations were considered to be stable or increasing in 77 percent of them (Halvorson *et al.*, 2021). They also indicated that honey bees were more frequently monitored than other pollinators and that while the government was mentioned as the monitoring agency in the majority of countries (61), beekeepers' associations were reported to be involved in monitoring in 50 countries and research organizations in 46, with all three of these categories reported to be involved in 40 percent of countries

[26] https://www.fao.org/dad-is/en

[27] https://www.fao.org/dad-is/data/en

and fewer than 20 percent of countries reportedly relying on a single actor (Halvorson *et al.*, 2021). The survey's findings on the number of countries with national monitoring systems for pollinators are shown in Table 2.

### 4.3.4. European Pollinator Monitoring Scheme

The proposal for the European Pollinator Monitoring Scheme (EUPoMS) was published in 2021 as a technical report led by the Joint Research Centre (JRC) in collaboration with a group of 21 experts from 12 European countries (Potts *et al.*, 2021). This report had the following objectives (wording taken directly from the report itself): "(i) develop a cost-effective Core Scheme which includes the most relevant taxa, is able to detect changes in the status of pollinators, has EU-wide coverage, and uses standardised sampling methods; (ii) provide a set of additional modules for other taxa and measures beyond the Core Scheme; (iii) propose a general EU indicator to assess status and trends of pollinators, and a Common Agricultural Policy specific indicator to evaluate the impacts of the CAP, and the measures implemented within, on both pollinators and pollination; and, (iv) provide estimated costs for establishing and implementing the Core Scheme, considering: staff, equipment, travel, taxonomic, training, data management and coordination costs."

The proposal thus provided a comprehensive methodology for monitoring pollinators in addition to suggesting potential indicators, including a tailored indicator for the EU Common Agricultural Policy. Subsequently, the EUPoMS held a consultation workshop (2021) that integrated stakeholder views on the current EU Pollinator Initiative and its proposed monitoring scheme. This was taken into consideration for the updated revised EU Pollinator Initiative released in 2023.

### 4.3.5. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) was established in 2012. It published the first global assessment of the importance of pollinators, pollination and food production, a report prepared by almost 80 expert authors and intended to inform decision-makers at all levels (IPBES, 2016). Although the global assessment has been important in the process of decision-making, it is not a legally binding policy or agreement. IPBES knowledge products have always been intended to be policy relevant and not policy prescriptive. FAO is one of four supporting UN agencies to IPBES; FAO provided technical oversight to the pollinator assessment process through the participation of FAO resource persons, provided review comments on the chapters and the summary for policymakers as part of the external review cycle and hosted an author meeting that facilitated author engagement and the finalization of the content. The IPBES pollinator assessment has a number of implications for the work of FAO (see, for example, FAO, 2016).

## 4.4 Stakeholders

Many groups of stakeholders are involved in, or influence, the management of invertebrate pollinators. They include international, regional, national and subnational authorities (including local authorities) overseeing invertebrate pollinator and/or insect-related issues (policymakers), fund and grant managers and representatives, land managers and farmers, civil society organizations, representatives of Indigenous Peoples and local communities, conservation groups, academia and researchers, and the business/corporate sector. This study does not attempt to categorize or discuss these groups in detail, but the following section provides an overview of the role of beekeepers' associations.

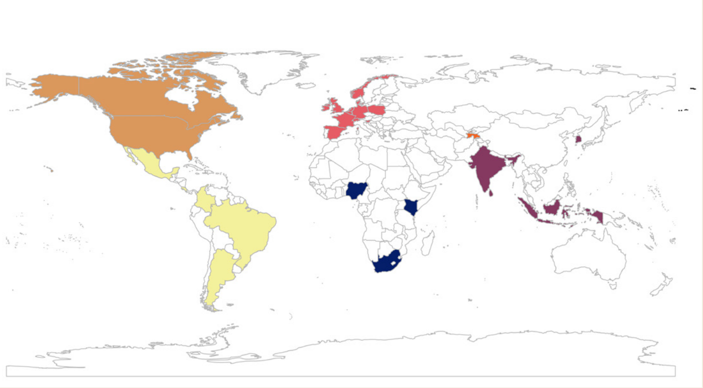
### 4.4.1. Professional beekeepers' associations

As honey bees make up a considerable part of pollinators, professional and hobby bee keepers and their associations are important stakeholders. Consideration of their views, including other stakeholder groups, can lead to more comprehensive policy formulation and close various knowledge gaps regarding honey bees and crop pollination (Breeze *et al.*, 2019). An example of a large beekeeper network is Apimondia.

Apimondia, the International Federation of Beekeepers' Associations,[28] is an example of a large beekeeper network. It was established in 1893 as the International Committee of Apicultural Congresses and held its first congress in 1897.[29] It has five "regional commissions" and seven "scientific commissions".

[28] https://www.apimondia.org
[29] https://www.apimondia.org/about.html

**Figure 19. Global distribution of countries with national pollinator strategies and initiatives**



*Source*: Authors elaboration for this background study paper. The map is based upon: UN Geodata Simplified, United Nations Geospatial, published April 13, 2023

**Table 3. Countries with national pollinator strategies and initiativess**

| Regions with total number of countries followed in brackets | | | | | | |
|---|---|---|---|---|---|---|
| **Africa (49)** | **Asia (25)** | **Europe (48)** | **Latin America and the Caribbean (33)** | **Near East and North Africa (21)** | **North America (2)** | **Southwest Pacific (16)** |
| Kenya | India | Belgium | Argentina | Tajikistan | Canada | |
| Nigeria | Indonesia | Denmark | Brazil | | United States of America | |
| South Africa | Republic of Korea | France | Colombia | | | |
| | Sri Lanka | Germany | Costa Rica | | | |
| | | Ireland | Mexico | | | |
| | | Luxembourg | | | | |
| | | Netherlands (Kingdom of the) | | | | |
| | | Norway | | | | |
| | | Poland | | | | |
| | | Slovenia | | | | |
| | | Spain | | | | |
| | | Switzerland | | | | |
| | | United Kingdom | | | | |
| 3 | 4 | 13 | 5 | 1 | 2 | 0 |

*Notes:* The count of countries with pollinator strategies or initiatives shown in the table (28) is less than the figure given in the main text for the number of national initiatives (30) because in the latter case Ireland and the United Kingdom of Great Britain and Northern Ireland are represented by four initiatives.

### Box 6. European Pollinator Initiative and European Pollinator Monitoring Schemes

The European Pollinator Initiative (EPI)* was established in 2000 under the first International Pollinator Initiative (IPI) to act as a coordinating body for local and national activities and as a conduit to the IPI. According to its mission statement, it aims to "protect and enhance the biodiversity and economic value of pollinators throughout Europe." It worked through regional projects such as the Assessing Large-scale Environmental Risks with Tested Methods (ALARM) (2004–2009),** which involved almost 80 partner institutes and organizations in measuring risks (economic and biodiversity-related), studying regional drivers affecting pollinators, and piloting standardized monitoring methods. Under the EPI, after the ALARM project was completed, the Status and Trends of European Pollinators (STEP) project continued the work (2010–2015)*** with seven specific objectives:

- "Document the status and trends of pollinator (managed honeybees, wild bees and hoverflies) and animal-pollinated plant populations;
- Determine and analyse the multiple pressures that are driving changes in pollinators and animal-pollinated plants at scales ranging from single fields to landscapes to the whole of Europe;
- Assess the impact of changes in pollinator populations and communities on wild plants and crops and changes in floral resources on pollinators;
- Evaluate and synthesize strategies to mitigate the impacts of changes in pollinators and animal-pollinated plants;
- Assess how multiple drivers affect pollinators and animal-pollinated plants at local and landscapes scales using focused empirical tests and observations;
- Analyse and improve the interface between the scientific knowledge-base on pollinator change assessment and policy instruments to reduce pollinator/pollination loss and mitigate its effects;
- Develop communication and educational links with a wide range of stakeholders and the general public on the importance of recent shifts in pollinators, the main drivers and impacts of pollinator shifts and mitigation strategies through dissemination and training."

EPI and both the above-mentioned projects provided evidence used in the preparation of the European Red List of Bees and the IPBES pollinator assessment. Both ALARM and STEP projects were funded by the European Commission. The success of EPI during the first IPI led to its continuance. In 2020, the European Commission – Joint Research Centre developed a proposal (Potts *et al*., 2021) for an EU Pollinator Monitoring Scheme to be part of the European Union (EU) Biodiversity Strategy (European Commission. Joint Research Centre, 2021). The EU Pollinator Monitoring Scheme proposes a cost-effective, pragmatic approach to monitoring several invertebrate pollinator taxa simultaneously using a standardized approach that could potentially also be used in other regions lacking baseline data on pollinators.

EPI is an example of how a well-coordinated regional pollinator initiative can have enormous benefits for the long-term goals of pollinator protection. Its achievements led to an updated version of the European Pollinator Initiative being adopted in June 2018 and a European Commission Directive consultation (European Commission Joint Research Centre, 2021).

*Source*: European Commission Joint Research Centre. 2021. *Proposal for an EU pollinator monitoring scheme*. LU, Publications Office. https://data.europa.eu/doi/10.2760/881843; Potts, S.G., Dauber, J., Hochkirch, A., Oteman, B., Roy, D.B., Ahme, K., Biesmeijer, J.C. *et al.* 2021. *Proposal for an EU Pollinator Monitoring Scheme*. JRC Technical Report. Ispra, EUR 30416 EN, Publications Office of the European Union.

* http://www.reading.ac.uk/AcaDepts/aa/epi/publish/EPI/
** http://www.alarmproject.net/
*** http://www.step-project.net/

## 4.5 Regional and national pollinator instruments and initiatives

### 4.5.1. Initiatives

Since the establishment of the International Pollinator Initiative, a number of regional and national pollinator initiatives have been developed. There are four regional initiatives (the African Pollinator Initiative, the European Pollinator Initiative [Box 6], the North American Pollinator Protection Campaign and the Oceania Pollinator Initiative). A fifth, the Asian Pollinator Initiative, is in the early stages of development. Thirty national initiatives[30] have been established or are in the process of being developed (Figure 19). These initiatives, however, are not being developed equally across regions and vary in scope and ambition. In North America, both Canada and the United States of America have national initiatives. In Europe and Central Asia, 15 countries have national initiatives (31 percent of the countries in the region).[31] In Latin America and the Caribbean, six countries have national pollinator strategies (18 percent of the countries in the region). In Asia, four countries have national pollinator initiatives (16 percent of the countries in the region). In Africa, three countries have national pollinator strategies (6 percent of the countries in the region). One country in the Near East and North Africa region has a national initiative (4.8 percent of the countries in the region). There are no national pollinator strategies in the Southwest Pacific region and the sole national pollinator strategy in the Near East and North Africa region is in its early stages of development (agreement to proceed with this national strategy occurred in 2021). Countries where there are national initiatives are listed in Table 3 and shown on the map presented in Figure 21. It is clear that initiatives are few and far between in several regions that are understudied and whose pollinators are vulnerable to risks that differ from those prevalent in the better-covered regions (see Figures 7 and 17), and this underscores the need to increase efforts to establish pollinator initiatives more widely.

The International Pollinator Initiative and the Plan of Action 2018–2030 for its implementation aim to support many actors, including Indigenous Peoples and local communities, in the implementation of the Conference of the Parties to the CBD's decision XIII/15. The importance of Indigenous Peoples is reflected in element A.2.4.5 of the Plan of Action 2018–2030 (Promote local and traditional knowledge related to innovative practices in management of honeybees, stingless bees and other managed pollinators). Dicks *et al.* (2016) list "Fund participatory research on improving yields in organic, diversified, and ecologically intensified farming" as one of ten policies that governments should consider adopting to protect pollinators. Approaches to safeguarding pollinators will only be effective if they are developed and implemented using participatory and inclusive decision-making processes.

The Indigenous Pollinators' Network[32] was established under the first International Pollinator Initiative following a training event on detecting pollinator deficits held in India in 2013 in collaboration with the Indigenous Partnership,[33] the Keystone Foundation[34] and other partners at the Community Production Centre in Bangalapadigai village (India). The success of this training event inspired local partners to form the Indigenous Pollinators' Network. In light of potential funding opportunities to support the activities of the Indigenous Pollinators' Network, new short- and long-term objectives for the network are being developed. The name of the network has also been changed to the Indigenous Peoples' Pollinator Network, and the intention is to continue joint activities with FAO under the second International Pollinator Initiative.

### 4.5.2. Findings of a global stocktake survey on initiatives, policies and instruments

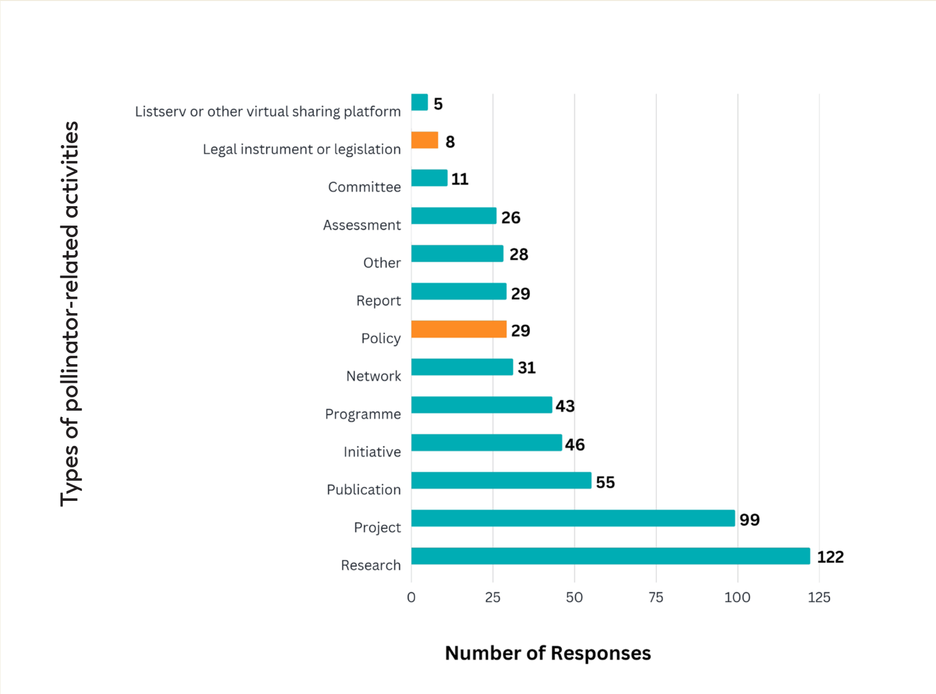
Significant progress has been made with research and international and national assessments (e.g. IPBES, 2016) on pollinators and pollination (Woloski *et al.*, 2018). However, many of these projects, activities, studies and initiatives are done in isolation.

To complement the desk-based review presented above, the preparation of the present study included a short survey aimed at providing a global stocktake of pollinator-related initiatives, policies and instruments around the world. It was recognized that the exercise would not provide a comprehensive stocktake, but the objective was to provide a more complete global picture of pollinator-related activities and policies at various scales. The results may not be fully representative geographically or topically. Respondents were invited to report on activities and policies (ongoing or under development) related to invertebrate pollinators and/or pollination.

[30] The figure includes four initiatives in Ireland and the United Kingdom (covering, respectively, all Ireland, England, Scotland and Wales).
[31] England, Ireland, Scotland and Wales are counted as four entities in these figures.

[32] https://www.theindigenouspartnership.org/pollinators-network
[33] https://www.theindigenouspartnership.org
[34] https://keystone-foundation.org

**Figure 20. Types of pollinator-related activities self-identified by respondents from the global stocktake questionnaire**




*Note*: Figures shown refer to submissions in all three languages: English, French and Spanish. A pollinator-related activity or policy could be reported under more than one category. The "Other" category includes educational activities, a task force, an exhibit, knowledge dissemination activity, germplasm collection activity, stewardship activity and hobby activity.

*Source*: Authors elaboration for this background study paper.

The survey, which was entitled *Questionnaire of existing initiatives, policies and instruments for the sustainable use and conservation of pollinator*, was developed using SurveyMonkey® and conducted between 8 February and 22 March, 2021 (approximately six weeks) in English, French and Spanish. The survey questionnaire (see Annex III) consisted of 20 questions (including those related to contact details and affiliations) and was intended to take less than ten minutes to complete. The questionnaire was made accessible via the Commission's website[35] and the FAO pollination website.[36] An invitation to complete the questionnaire was sent to all National Focal Points (NFPs) for biodiversity for food and agriculture and for the Commission as well as to NFPs for various relevant sectors.[37] The questionnaire was also published on the Promote Pollinators homepage[38] and publicized via the Promote Pollinators e-newsletter, the UNDP Bes-NET e-newsletter and website,[39] and several pollinator-related listservs.[40] The call to participate in the questionnaire was also circulated via FAO social media accounts and several other social media accounts (e.g. IPBES' twitter

[35] http://www.fao.org/cgrfa/topics/biodiversity/pollinators/en/
[36] http://www.fao.org/pollination/en/

[37] NFPs for the Commission act as countries' liaisons with the Secretary of the Commission. NFPs for biodiversity for food and agriculture and for the various sectors of genetic resources for food and agriculture serve as countries' contact persons for communication with the Commission and FAO regarding work on the respective components of biodiversity.
[38] https://promotepollinators.org/fao-survey-sustainable-use-and-conservation-of-pollinators/
[39] https://www.besnet.world/invitation-faos-survey-sustainable-use-pollinators
[40] icppr-l@listserv.UMD.edu, polpal-l@googlegroups.com, CROPROPOL-L@listsrv.bio.bg.ac.rs, and beemonitoring@googlegroups.com

**Box 7. Policy integration between Healthy Bees Plan 2030 and Action Plan for Pollinators in Wales**

Currently, invertebrate pollinators in Wales and their conservation are delineated between managed bees and wild bees and are under the authority of two government units: managed honey bees and issues related to beekeeping are overseen by the National Bee Unit (NBU) on behalf of the Welsh Government and the (United Kingdom's) Department for Environment, Food & Rural Affairs (Defra) and wild pollinators are under the responsibility of Natural Resources Wales. The latter is the Welsh Government's largest sponsored body on "statutory advisory on nature conservation" – the latest remit issued to Natural Resources Wales emphasizes work on climate change and renewable energy and on halting and reversing the decline in nature, especially through woodland management and restoring peat bogs (Welsh Government, 2020).

The Healthy Bees Plan 2030 (Welsh Government, 2020) covers England and Wales and was launched in 2020 as update to the Healthy Bee Plan published in 2009. It is published on a website called BeeBase[*] that provides information for beekeepers on diseases, pests and environmental threats to honey bees, among other topics.

The Action Plan for Pollinators in Wales was published in 2013 (Welsh Government, 2013). While the Action Plan contains subsections on honey bees and their status, it also focuses on wild pollinators. Within the Action Plan on Pollinators, it explicitly states that there is no one central body responsible for overseeing pollinator protection and providing information on pollinators. The Action Plan on Pollinators also recognizes other cross-cutting government strategies that involve pollinators and aims to integrate action for the conservation of all these other strategies and action plans within the Welsh Government.

*Source*: Welsh Government. 2020. *Healthy Bees Plan 2030: Working together to improve honey bee health and husbandry in England & Wales*. Department for Environment, Food and Rural Affairs. https://www.nationalbeeunit.com/assets/PDFs/4_Bee_Health_Improvement/HBP_2030/HBP2030_English_language_version.pdf; Welsh Government. 2013. *The Action Plan for Pollinators in Wales*. Land, Nature and Forestry Division, Welsh Government. Welsh Government Publication, Aberystwyth, UK.; The Llywodraeth Cymru Welsh Government: https://www.gov.wales/sites/default/files/publications/2019-04/action-plan-for-pollinators.pdf; https://www.gov.wales/sites/default/files/publications/2019-04/action-plan-for-pollinators-review-and-future-actions-en.pdf

[*] https://www.nationalbeeunit.com/

account,[41] which had almost 19 000 impressions). By 22 March 2021, 224 responses from 161 respondents (168 English, 47 Spanish, 9 French) had been received.

Figure 20 presents the distribution of the types of pollinator-related activities and policies reported by respondents. The focus here is on activities and policies reported under the categories "Policy" and "Legal instrument or legislation". The types of activity reported under "Policy" included national pollinator protection strategies (see also below and Section 4.5.1) and federal pesticide policies, or policies addressing, *inter alia* the following topics: *Bombus terrestris* as an invasive alien species and its breeding, import, transfer and potential impact on other pollinators; monarch butterflies; honey bees (beekeeping) and honey production; and plant protection. Some of the activities reported under "Policy" and "Legal instrument or legislation" were not themselves policies or legal instruments. They included, for example, publications and projects on policy-relevant topics, a state-level interagency pollinator protection team that develops cross-agency policies and programmes, a municipal lawn-pesticide regulation, a municipal initiative for reducing lawn mowing to benefit pollinators, incentive or insurance schemes for farmers, "green infrastructure" in agricultural and urban landscapes, and monitoring. The instruments reported under these categories varied in scale and in terms of implementing authority (i.e. from municipal legislation to national/federal legislation). The national pollinator strategies reported as policies or legal instruments were those from Brazil, Colombia, Mexico, England, France and Wales (Box 7) – all of which are covered in Section 4.5.1.

[41] https://twitter.com/IPBES/status/1359117041408557058

**Table 4. Summary of output results from search terms entered into the FAOLEX database**

| Search term in FAOLEX | Number of output results |
|---|---|
| bees | 604 |
| bee_* | 407 |
| beekeeping | 192 |
| Apis | 122 |
| abeja | 119 |
| abeille | 56 |
| apiary | 67 |
| apiculture | 1707 |
| apicultura | 129 |
| meliponiculture | 2 |
| meliponicultura | 4 |
| Melipona | 10 |
| Osmia | 0 |
| Bombus | 9 |
| Megachil* | 0 |
| bumble | 34 |
| pollination | 70 |
| pollinator | 13 |
| polinizador* | 7 |
| pollinisateur | 5 |
| pollinisation | 2 |
| polinización | 15 |
| Total | 3 574 |

*Notes:* Search results were not sensitive to use of capitals or italics in search words.

### 4.5.3. Analysis of pollinator-related policies, legislation and regulations recorded in FAOLEX

FAOLEX is a comprehensive and up-to-date legislative and policy database on food and agriculture, one of the world's largest online repositories of national laws, regulations and policies on food, agriculture and natural-resources management. The FAOLEX data portal allows access to abstracts and indexing information about all policies, legislation and regulations.

FAOLEX "contains legal and policy documents drawn from more than 200 countries, territories and regional economic integration organizations and originating in over 40 languages." The FAOLEX database further states that within each entry - the key elements of each legal or policy document are summarized in English, French or Spanish and indexed to facilitate search and retrieval.

At the time of the analysis undertaken for the present study FAOLEX contained 184 964 records. The following search terms were used to extract relevant records : "bees", "bee_*", "beekeeping", "Apis", "abeja", "abeille", "apiary", "apiculture", "apicultura", "meliponiculture", "meliponiculture", "Melipona", "Osmia", "Bombus", "Megachil*", "bumble", "pollination", "pollinator", "polinizador*", "pollinisateur", "pollinisation" and "polinización".

Table 4 presents a summary of output results from search terms. Assuming search terms are weighed evenly in the database and ignoring duplicates, the search resulted in a total of 3 574 output results with over half of those (1 946) related to beekeeping and apiculture. These output results represent a total of 1 946 records (including duplicates) extracted from the FAOLEX database. Removing 363 duplicate records left 1 583 records for use in the analysis.

According to the categories used in FAOLEX, 963 of the records were regulations (60.8 percent), 465 were legislation (29.4 percent), 106 were policies (6.7 percent), 21 were classified as miscellaneous (1.3 percent), 18 were agreements (0.01 percent), 7 were classified as regulation/policies (0.4 percent) and 3 were classified as miscellaneous/regulations (0.2 percent). While a more in-depth analysis of the themes of each policy, item of legislation or regulation remains to be conducted, the results presented in Table 4 indicate an emphasis on beekeeping and apiculture compared to other topics, such as wild pollinators. A search for the keyword "pesticide*" in the FAOLEX database generated 2 949 output results. While further analysis of the 1 583 records remains to be conducted, a first overview indicates that these policies, items of legislation

**Table 5. Subnational administrative divisions with pollinator-related policies, legislation or regulations recorded in FAOLEX**

| Country | Administrative division(s) |
|---|---|
| Argentina | Catamarca, Córdoba, Corrientes, Formosa, La Pampa, Mendoza, Río Negro, Santa Fe and Tucumán |
| Australia | Australian Capital Territory, New South Wales, Queensland, South Australia, Tasmania, Western Australia |
| Austria | Kärnten, Niederösterreich, Oberösterreich, Salzburg, Tirol, Vorarlberg, Wien |
| Belgium | Wallonia |
| Bosnia and Herzegovina | Federation BiH, Republika Srpska |
| Botswana | Central District, Kgalagadi District |
| Brazil | Alagoas, Amapá. Amazonas, Bahia, Distrito Federal, Espírito Santo, Maranhão, Mato Grosso do Sul, Mato Grosso, Minas Gerais, Pará, Paraíba, Paraná, Rio Grande do Norte, Rio Grande do Sul, Rondônia, Roraima, Santa Catarina |
| Canada | Alberta, British Columbia, Manitoba, New Brunswick, Newfoundland, Nova Scotia, Ontario, Prince Edward Island, Québec, Saskatchewan |
| China | Taiwan Province of China |
| Germany | Baden-Württemberg, Bayern, Brandenburg, Hessen, Mecklenburg-Vorpommern, Niedersachsen, Rheinland-Pfalz, Sachsen, Sachsen-Anhalt, Schleswig-Holstein, Thüringen |
| India | Andhra Pradesh, Himachal Pradesh, Meghalaya |
| Iraq | Kurdistan Region (no federal policies, legislation or regulations reported for Iraq) |
| Italy | Abruzzo, Basilicata, Bolzano, Calabria, Campania, Emilia-Romagna, Friuli-Venezia Giulia, Lazio, Liguria, Lombardia, Marche, Molise, Piemonte, Puglia, Sardegna, Sicilia, Toscana, Trentino-Alto Adige, Trento, Umbria, Veneto |
| Kenya | Kilifi, Meru |
| Mexico | Aguascalientes, Baja California Sur, Campeche, Chiapas, Chihuahua, Coahuila de Zaragoza, Colima, Durango, Guanajuato, Hidalgo, Jalisco, Michoacán de Ocampo, Morelos, Nuevo León, Oaxaca, Puebla, Quintana Roo, Sinaloa, Sonora, Tabasco, Tamaulipas, Tlaxcala, Veracruz-Llave, Yucatán, Zacatecas |
| Norway | Svalbard |
| Pakistan | Punjab |
| Portugal | Azores |

| Country | Administrative division(s) |
|---|---|
| Russian Federation | Adygeya, Altai, Amur, Archangel, Bashkortostan, Belgorod, Chuvashia, Ingushetia, Ivanovo, Kaliningrad, Kaluga, Karachayevo-Cherkessia, Karelia, Khabarovsk, Khakassia, Kostroma, Krasnodar, Kurgan, Kursk, Leningrad, Nizhni Novgorod, Novosibirsk, Orel, Orenburg, Penza, Primorie, Pskov, Rostov, Samara, Saratov, Stavropol, Tatarstan, Trans-Baikal, Tula, Tuva, Tyumen, Udmurtia, Volgograd, Vologda, Voronezh, Yaroslavl |
| Switzerland | Aargau, Appenzell Ausserrhoden, Fribourg, Genève, Glarus, Graubünden, Neuchâtel, Valais, Zürich |
| United Arab Emirates | Abu Dhabi |
| United Kingdom of Great Britain and Northern Ireland | England, Great Britain, Northern Ireland, Scotland, Wales |
| United States of America | Alabama, California, Florida, Virginia |

and regulations seem to focus on only a handful of drivers impacting pollinators and pollination services (see Annex IV). The 1 583 records originated from 183 countries or regions.

The distribution of pollinator-related policies, legislation and regulations, even at subnational level, is irregular (i.e. the distribution of subnational policies, legislation and regulations is not even across all states or provinces within countries nor are they evenly distributed across all states or provinces. Table 5 presents pollinator-related policies, legislations or regulations at subnational (province or state) level that some countries have in addition to national/federal level ones. FAOLEX records for countries not included in the table only include national/federal level pollinator-related policies, legislations and regulations (for example, Azerbaijan, Bangladesh, Belarus, the Plurinational State of Bolivia, Chile, Colombia, etc.). This table demonstrates the variation in responsibility/authority for pollinator-related issues across countries and within a country.

Pollinator-related policies, legislation and regulations recorded in FAOLEX are not distributed evenly across regions (Figure 24): (in decreasing order of share of total pollinator-related policies, legislation and regulations) 53 percent are in Europe and Central Asia; 18.7 percent are in Latin America and the Caribbean; 9.9 percent are in Africa; 5.2 percent are in the Near East and North Africa; 4 percent are in North America; 4 percent are in Asia; 3 percent are in the Southwest Pacific; and 2 percent cover clusters of countries that are not all within a single region.

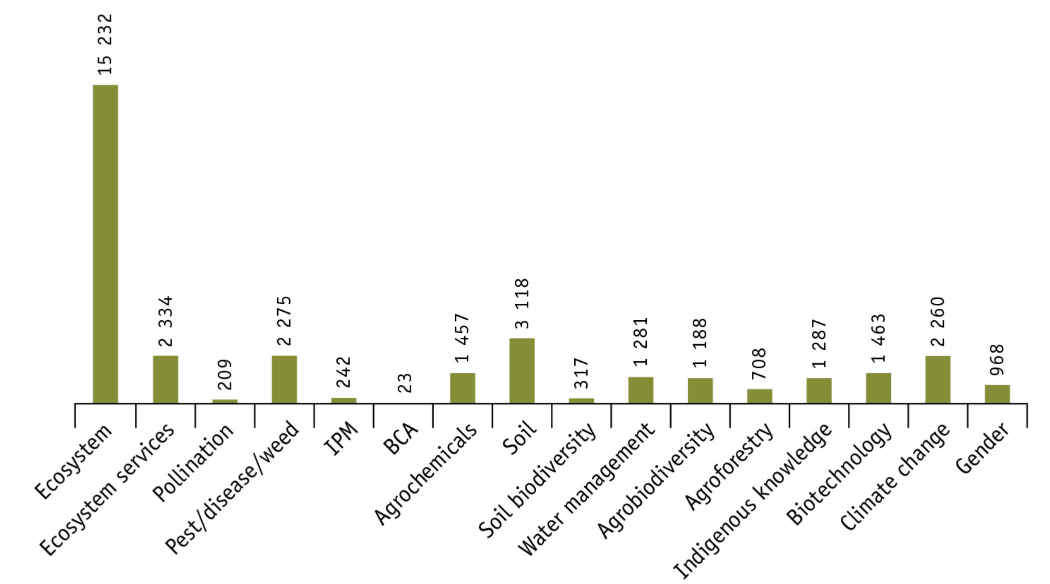
While an increasing number of countries have adopted national pollination strategies (see Section 4.5.1), pollinator-related issues are usually not addressed by a single dedicated law or regulation. Instead, they are usually integrated/mainstreamed in, or covered by, national laws of various kinds, such as those addressing endangered species, the authorization and use of pesticides, trade in bee products such as honey or livestock breeding. Administrative responsibility for such laws often lies with different government agencies at national and regional levels (see Table 5 and Box 7). National laws specifically addressing pollinators usually focus on honey bees in the context of beekeeping (e.g. covering trade, biosecurity, pests/diseases, hive products or breeding regulations): see for example Case Studies 1 and 2 in Section 4.5.4. The disparity in pollinator-related competences often makes the development and implementation of a coordinated strategy for the protection of pollinators difficult and cumbersome.

All scales of pollinator-related policies, legislation and regulations play important roles in pollinator conservation. However, they can be counterproductive if they are not integrated and coherent. National and subnational policy analyses can inform decision-makers about policy trends or highlight policy gaps at different levels and encourage policy integration, both vertically and horizontally.

### 4.5.4.National biodiversity strategies and action plans and pollinators

NBSAPs are a major component of framework for the implementation of the CBD and CBD COP decisions at national scale. Article 6 of the CBD (General Measures for Conservation and Sustainable Use) states that:

**Figure 21. Number of mentions of selected keywords contained in 166 national biodiversity strategies and action plans**




*Source*: FAO and CBD. 2016. *Mainstreaming Ecosystem Services and Biodiversity into Agricultural Production and Management in East AFRICA*. Rome: FAO and Secretariat of the Convention on Biological Diversity. http://www.fao.org/3/a-i5603e.pdf.

*Each Contracting Party shall, in accordance with its particular conditions and capabilities:*

*(a) Develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes which shall reflect, inter alia, the measures set out in this Convention relevant to the Contracting Party concerned*

*(b) Integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies.*[42]

Article 6 is supported by Article 10 (Sustainable Use of Components of Biological Diversity), which states that:

*Each Contracting Party shall, as far as possible and as appropriate:*

*(a) Integrate consideration of the conservation and sustainable use of biological resources into national decision-making.*[43]

[42] Convention on Biological Diversity. Article 6. General Measures for Conservation and Sustainable Use. 5 June 1992 and https://www.cbd.int/nbsap/introduction.shtml

[43] https://www.cbd.int/convention/articles/?a=cbd-10

Almost all Parties to the CBD have developed at least one NBSAP (192 out of 196, or 98 percent)[44] and approximately half have revised or updated their NBSAPs (i.e. have produced more than one edition). In 2016, FAO and the CBD analysed 166 NBSAPs, in English, French, Spanish and Portuguese (FAO and CBD, 2016). This report examined how a range of topics were referred to within NBSAPs. Results of the analysis are presented in Figure 21. The number of mentions of “pollination” was relatively low compared to mentions of “agroforestry” or “biotechnology”, for example.

Uetake *et al.* (2019), similarly, conducted an analysis of the coverage of production landscape policies in NBSAPs by text mining 133 NBSAPs. Using various keyword searches, they found that approximately half the NBSAPs studied mentioned integrated approaches in production landscapes and that there were regional differences in the occurrences of the keywords within NBSAPs. A total of 39 503 paragraphs and 167 945 sentences were analysed. The authors report that the most frequently used terms were “biodiversity” (31 209 times), “species” (23 801 times), “area” (21 604 times) and “conservation” (18 113 times). The results of the sentence-analysis are shown in Table 6.

[44] https://www.cbd.int/nbsap/

**Table 6. Results of an analysis of the number of sentences in national biodiversity strategy and action plans referring to each code (term)**

| Group | Code | Number of sentences referred to the codes |
|---|---|---|
| A1 | GIAHS | 3 |
| | SEPLS | 11 |
| | Cultural landscape | 49 |
| A2 | Traditional natural resources management | 306 |
| A3 | Landscape approach | 21 |
| B | Dynamic mosaics of habitats and land and sea uses | 26 |
| | Harmonious intereaction between people and nature maintains biodiversity | 266 |
| | Providing humans with the goods and services in a sustainabel matter | 810 |
| | Be deeply linked to local culture and knowledge | 1 996 |
| C | Ecosystem approach | 312 |
| D | Landscape | 1 960 |
| | Seascape | 117 |

*Notes:* SEPLS = socio-ecological production landscapes. GIAHS = Globally Important Agricultural Heritage System. Number of national biodiversity strategy and action plans analysed = 133. Number of sentences analysed = 39 503.

*Source:* Uetake, T., Kabaya, K., Ichikawa, K., Moriwake, N. & Hashimoto, S. 2019. Quantitative analysis of national biodiversity strategy and action plans about incorporating integrated approaches in production landscapes. *Journal of Environmental Planning and Management*, 62: 1–25. https://doi.org/10.1080/09640568.2018.1530202

The approach used differed from that used in the above-mentioned FAO and CBD (2016) study and so direct comparisons between the results of the two studies are not possible.

As noted above, NBSAPs are key policy tools for biodiversity conservation and there may be currently no or little acknowledgement of the importance of pollinators and/or pollination services within NBSAPs. Preliminary (basic) qualitative content analysis using QSR's NVivo 10.0 software was used in the textual analysis (text mining) of NBSAPs to gain perspective on the global state of pollinators within these policy tools. This section explains the approach to using qualitative content analysis to characterize inclusion of pollinators as an indicator of recognition in national policy tools such as NBSAPs.

The preliminary analysis was only conducted on NBSAPs available in English, but future analyses could incorporate more languages. The NBSAPs accessed were available on the CBD website,[45] as of July 2021. The analysis included 173 NBSAPs from 117 member countries, as some countries have produced more than one version of their NBSAP, and analysis was not limited to the latest versions. The following keywords were searched for "bee/s", "beekeeping", "pollinators" and "pollination". Future analyses could include other keywords. NBSAPs that could not be read by the software because of the low scan-quality of the uploaded versions were excluded from the analysis.

The analysis of 173 NBSAPs found an average of only 0.0142 percent inclusion of the words "bee/s", "beekeeping", "pollinators" or "pollination". This indicates relatively little acknowledgement of the critical importance that pollinators and pollination

[45] https://www.cbd.int/nbsap/

**Table 7. Summary of the coverage of pollinator-related policy recommendations in laws and policies in Brazil and the United States of America**

| Policy recommendation | Number of laws from the United States that addressed each policy recommendation | Number of references to the theme across all laws in the United States of America | Number of Brazilian laws that addresses each policy recommendation | Number of Brazilian policies addressing themes/targets | |
|---|---|---|---|---|---|
| | | | | Addresses only one target only | Addresses ≥1 target within the same law |
| 1. Raise pesticide regulatory standards | 24 | 38 | 132 | 136 | 1a |
| 2. Promote integrated pest management | 0 | 0 | 0 | | |
| 3. Include indirect and sublethal effects in genetically modified crop risk assessments | 0 | 0 | 0 | | |
| 4. Regulate movement of managed pollinators (i.e. related to beekeeping) | 0 | 0 | 35 + 9 (Meliponiculture practices) | 10 | 2b, 1f |
| 5. Develop incentives, such as insurance schemes, to help farmers benefit from ecosystem services instead of agrochemicals | 2 | 3 | 59 (Economic aspects) | 2 | 3c, 1d, 7e |
| 6. Recognize pollination as an agricultural input in extension services | 1 | 1 | 0 | 3 | 2b, 1f |
| 7. Support diversified farming systems | 54 | 96 | 0 | 3 | 1a, 1d, 7e, 1f |
| 8. Conserve and restore “green infrastructure” in agricultural and urban landscapes | 23 | 48 | 17 | | 4 |
| 9. Develop long-term monitoring of pollinators and pollination | 7 | 11 | 0 | | |

| Policy recommendation | Number of laws from the United States that addressed each policy recommendation | Number of references to the theme across all laws in the United States of America | Number of Brazilian laws that addresses each policy recommendation | Number of Brazilian policies addressing themes/targets |
|---|---|---|---|---|
| 10. Fund participatory research on improving yields in organic, diversified, and ecologically intensified farming | 18 | 22 | 0 | 3c, 7e |
| 11. Awareness* | 32 | 43 | 62 | 29 |
| 12. Other* | 48 | 66 | 0 | 5 (pollinator habitats) |

*Notes:* Policy recommendations are taken from Dicks *et al.*, 2016). 109 subnational laws in the United States of America (Hall and Steiner, 2019) and 314 national subnational laws in Brazil (Hipólito *et al.*, 2021) are covered. In the far-right column, each figure represents a count of the number of policies addressing a given combination of targets or themes. These combinations are indicated by the letters adjacent to the numbers (e.g. the appearance of "1a" in both the row related to pesticide regulatory standards and the row related to supporting diversified farming indicates that there is one policy that addresses both these themes).

*Sources:* Dicks, L.V., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M. del C., Cunningham, S.A., Galetto, L. *et al.* 2016. Ten policies for pollinators. *Science*, 354(6315): 975–976. https://doi.org/10.1126/science.aai9226; Hall, D.M. & Steiner, R. 2019. Insect pollinator conservation policy innovations at subnational levels: Lessons for lawmakers. *Environmental Science & Policy*, 93: 118–128. https://doi.org/10.1016/j.envsci.2018.12.026; Hipólito, J., Coutinho, J., Mahlmann, T., Santana, T.B.R. & Magnusson, W.E. 2021. Legislation and pollination: Recommendations for policymakers and scientists. *Perspectives in Ecology and Conservation*, 19(1): 1–9. https://doi.org/10.1016/j.pecon.2021.01.003

play in achieving many conservation objectives, but at the same time highlights the large potential for increasing awareness among decision-makers. The preliminary analysis of search words within text has the following additional themes (not yet quantified or summarized): livestock and beekeeping, apiculture, honey-bee products, pesticides and pollination (only in the context of describing ecosystem services and not the ecosystem service itself as being acknowledged).

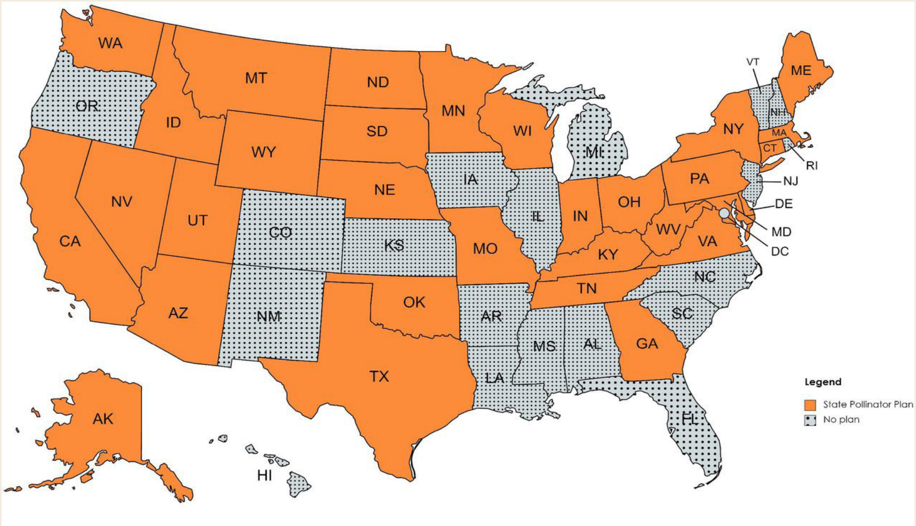
An update or revision of an NBSAP can create an important opportunity to link the conservation and sustainable use of pollinators to existing national policies and to international policies, conventions and instruments. Implementing actions and appropriate measures written in NBSAPs to achieve the goals and targets of the CBD and the Kunming-Montreal global biodiversity framework would also enable the achievement of the International Pollinator Initiative.

There are a growing number of national and subnational pollinator strategies. Case studies from the United States of America and Brazil are presented below. They show that there are opportunities for further coordination even within individual countries.

**Case Study 1: Subnational pollinator strategies in the United States of America**

In June 2014, President Obama issued a memorandum on creating a Federal Strategy to Promote the Health of Honey Bees and Other Pollinators (The White House, 2014), which included the creation of a Pollinator Health Task Force. The mandate was spread across several departments and agencies, including the Department of Agriculture, the Department of the Interior, the Department of Defense and the Environmental Protection Agency. The strategy was published in 2015 (Pollinator Health Task Force, 2015). The strategy had three overarching goals: "1) **Honey Bees**: Reduce honey bee colony losses during winter (overwintering mortality) to no more than 15 percent within 10 years. This goal is informed by the previously released Bee Informed Partnership

**Figure 22. Distribution of state pollinator plans in the United States of America**




*Note*: Preprint from bioRxiv, 16 Jun 2021. DOI: 10.1101/2021.06.15.447774 PPR: PPR357479).

*Source*: Whitney, K.S. & Stringer, B.B. 2021. *Evaluation of US state pollinators using 3 evidence-based policymaking frameworks.* bioRxiv. Cited 2 June 2023. https://www.biorxiv.org/content/10.1101/2021.06.15.447774v1

surveys and the newly established quarterly and annual surveys by the United States Department of Agriculture National Agricultural Statistics Service. Based on the robust data anticipated from the national, statistically based NASS surveys of beekeepers, the Task Force will develop baseline data and additional goal metrics for winter, summer, and total annual colony loss. 2) **Monarch Butterflies**: Increase the Eastern population of the monarch butterfly to 225 million butterflies occupying an area of approximately 15 acres (6 hectares) in the overwintering grounds in Mexico, through domestic/international actions and public-private partnerships, by 2020. 3) **Pollinator Habitat Acreage**: Restore or enhance 7 million acres of land for pollinators over the next 5 years through Federal actions and public/private partnerships."

Since the establishment of this federal strategy and the task force, a total of 109 subnational pollinator-related policies were passed by 36 of the country's state legislatures between 2000 and 2017 (meaning that 14 states did not pass any such policies) (Hall and Steiner 2019).

Whitney and Stringer (2021) found that 31 of 50 states had developed a state pollinator protection plan since the national strategy to promote the health of honey bees and other pollinators was published (Figure 22). They found that most states that had established a pollinator protection plan lacked a process for implementing it and that the state plans varied in quality and scope. The rapid establishment of the national and state pollinator strategies demonstrates public concern about pollinators and public awareness of pollinator-related issues (Hall and Martins, 2020). State laws have the potential to provide an effective "bottom-up" approach if they are appropriately coordinated and harmonized.

The overarching three objectives of the national strategy (relating respectively to honey bees, monarch butterflies and increasing pollinator habitat area) do not closely align with the ten policies for pollinators that emerged from the IPBES pollination report (Dicks *et al.*, 2016) or with the emphasis of the state laws (Table 3.2 ) (e.g. none of the state laws address regulations involving the movement of managed pollinators, which is a priority under the federal strategy). The prompt establishment of 31 state pollinator protection plans was a great step forward for pollinator conservation at state level. The plans could be expanded to include additional elements (e.g. opportunities for action) and harmonized and aligned with those of neighbouring states and with those of states across the whole country.

**Case Study 2: Brazil and its subnational pollinator strategies**

An analysis of national and subnational Brazilian legislation concerning pollinator-relevant policies from the period between1967 and 2019 was conducted to examine the alignment of these policies with the existing evidence base (i.e. how well-informed the policies were) (Hipólito *et al.*, 2021). The set of 314 laws assessed related to the themes of apiculture, meliponiculture, economic matters (such as taxes or financial incentives for bees), pesticides, pollinator awareness and city planning. These laws do not address some of the pollinator-related recommendations identified by Dicks *et al.* (2016) or elements of the International Pollinator Initiative's Plan of Action 2018–2030, such as non-bee pollinators, IPM, risks associated with genetically modified (GM) crops, and long-term monitoring of pollinators and pollination. An analysis of the spread of pollinator-related legislation showed that a disproportionate number were concentrated in the country's Northeastern region, which is the location of 113 of the 314 laws; Rio de Janeiro was the state that had the highest number of laws or other items of legislation related to pollinators and awareness. Hipólito *et al.* (2021) state that differences between the legislation in different regions and states within Brazil result in a lack of integration among the country's pollinator protection policies.

# Chapter 5. Opportunities for action

## 5.1 Gaps and needs

The chapters above identify scientific and technical gaps (Chapters 1 to 3) and gaps in policy, legislation and regulations (Chapter 4). Identifying such gaps can help guide governance actions to close these gaps for better policy and practices that lead to more effective conservation of invertebrate pollinators, including honey bees.

Despite the tremendous efforts made by the research community in recent decades, there are still significant gaps in research on, and knowledge of, invertebrate pollinators and pollination services. Chapters 1 and 2 highlight many of the scientific and technical gaps that still exist for invertebrate pollinators, drawing on the IPBES (2016) pollinator assessment and other publications (Hanley *et al.*, 2015; Saunders *et al.*, 2019; Dicks *et al.*, 2021).

Knowledge gaps that emerge from the study include those in the following areas:

- data on bee distributions are highly heterogeneous, with records largely missing for most of Asia, Africa, the Near East and parts of South America;
- bee data on abundance and long-term population trends are generally lacking globally;
- understanding of the most proximate causes of pollinator decline associated with habitat loss and fragmentation is limited, despite e.g. Africa, the impact of land-use change (cover and configuration) on pollinators and their subsequent impacts on people and their well-being are still largely unknown;
- the impact of multiple drivers and threats on pollinators (e.g. climate change plus other drivers);
- the impact of management practices on all invertebrate pollinators and pollination services; particular requirements include:
    - meta-analyses on the effects of organic farming on pollinators, pollination and crop yield,
    - the effect of reducing pesticides (ecological intensification) on both crop productivity and pollinator populations,
    - changes to the resilience of pollinator populations and communities following the application of ecological intensification interventions;
- direct and indirect effects of honey bees and other managed bees (including stingless bees) on wild plants and wild pollinators via competition and pathogen spillover;
- more information on the sublethal effects of chemicals (pesticides and other environmental pollutants) on wild pollinators;
- the status and trends of floral-resource availability (at a landscape scale) and their impacts on pollinators;
- the habitat creation measures that can best help restore pollinator populations in rural and urban landscapes;
- the factors that affect pollinator movements through landscapes;
- the market and non-market values of pollinators and pollination;
- the evaluation of agricultural productivity and ecosystem services over the long term; and
- an evaluation of multiple benefits of pollinator-friendly habitats.

These knowledge gaps are not equally distributed across regions. For example, data on bee distribution are highly heterogeneous, with records largely missing for most of Asia, Africa, the Near East and parts of South America, although data on abundance and population trends are generally lacking globally. Global assessments such as the IPBES pollinator assessment are one-off undertakings and cannot be used for regular monitoring.

Basic information on diversity, abundance, richness and occurrence is lacking for invertebrate pollinators (Didham *et al.*, 2020; Dicks *et al.*, 2021) because of taxonomic challenges (Habel *et al.*, 2019) and the absence of standardized monitoring protocols. Efforts to address both these issues could be complemented and supported by citizen scientists (Garrett *et al*, 2019).In earlier FAO work, several collecting and monitoring protocols were developed and implemented in the field to test for feasibility of the approach such as the Protocol to detect and monitor pollinator communities: guidance for practitioners (LeBuhn *et al*., 2016a;b) and the *Rapid assessment of pollinators' status: a contribution to the international initiative for the conservation and sustainable use of pollinators* (FAO, 2008) in recognition of these knowledge gaps due to systematic collecting and monitoring of invertebrate pollinators.

In 2022, the European Commission – Joint Research Centre developed a proposal for an EU Pollinator Monitoring Scheme within the EU Biodiversity Strategy. The proposed scheme, which emerged from activities conducted under the European Pollinator Initiative (Box 6), would provide a cost-effective, pragmatic approach to monitoring several invertebrate pollinator taxa simultaneously using a standardized approach. Implementing this standardized approach in other regions lacking baseline data on pollinators would enable direct comparisons of pollinator data and could help inform decision-making.

In terms of drivers, understanding of the most proximate causes of pollinator decline associated with habitat loss and fragmentation is limited, despite land-use change having been identified as the largest risk to pollinators. For example, in Africa, the impact of land-use change (cover and configuration) on pollinators and their subsequent impacts on people and their well-being are still largely unknown. The impact of some single drivers on pollinators and pollination services is not well known, l*et al*one the impact of multiple drivers and threats on pollinators (e.g. climate change plus other drivers). Lastly, knowledge and studies on the impact of management practices on all invertebrate pollinators and pollination services are also lacking, including in the following areas: meta-analyses on the effects of organic farming on pollinators, pollination and crop yield; the effect of reducing pesticides (ecological intensification) on both crop productivity and pollinator populations; changes to the resilience of pollinator populations and communities following the application of ecological intensification interventions; and the direct and indirect effects of honey bees and other managed bees (including stingless bees) on wild plants and wild pollinators via competition and pathogen spillover.

Pollinators are declining worldwide, albeit at different rates in different regions. Their loss and the impact this has on human well-being justifies calls for stronger governance around pollinator conservation.

There is a persistent gap between science, practice and policy, mainly caused by a lack of coordination and communication between scientists, practitioners and policymakers. Policies are developed and implemented at various scales, and any action to safeguard invertebrate pollinators is encouraged. For pollinator-related policy, legislation and regulations there should be better policy integration[46] between different pollinator-related policies, laws and regulations, which can lead to design and implementation challenges related, for example, to policy capacity (especially at subnational levels of government), power dynamics (i.e. state agencies responsible for "second-order policymaking and implementation") (Wurtzebach *et al*., 2018; Hall and Steiner, 2019), and competing interests within and across levels of government.

A review of pollinator-related policies, regulations and legislation indicates a governance gap arising from the lack of an overarching international body overseeing the global framework (both binding and non-binding agreements and instruments) for the protection of pollinators and pollination services.

To date, the responsibility for pollinator-related issues lies with different bodies and instruments, and there is no dedicated forum at global level that reviews the status of pollinators at regular intervals, coordinates the exchange of knowledge and experiences in a systematic way and aims to ensure coordinated action across relevant fora and instruments.

The International Pollinator Initiative has led to significant and noteworthy progress, and this is reflected in many national and subnational initiatives, projects and laws addressing pollinators. At regional scales, there are examples of significant progress and outcomes being achieved when a large number of institutes and organizations cooperate and projects are well-funded, for instance in the case of the European Pollinator Initiative and associated projects (see Box 6).

The situation at national level is similar to that at international level. While an increasing number of countries have adopted national pollination strategies, pollinator-related issues are usually not addressed by a single dedicated law or regulation. Instead, they are usually integrated or mainstreamed into, or covered by, national laws of various kinds, such as those addressing endangered species, the authorization and use of pesticides, trade in bee products such as honey, or livestock breeding. Administrative responsibility for such

[46] Policy integration is defined as goals and tools integrated at one level and across levels of governance (Howlett and Del Rio, 2015. https://doi.org/10.1177/0263774X15610059).

laws often lies with different government agencies at national and regional levels. National laws specifically addressing pollinators usually focus on honey bees in the context of beekeeping (trade, biosecurity, pests/diseases, hive products, breeding regulations, etc.). The disparity in pollinator-related competences often makes the development and implementation of a coordinated strategy for the protection of pollinators difficult and cumbersome.

NBSAPs are policy instruments for framing the aims and objectives of the CBD in national contexts and guiding national actions. However, the findings of the survey undertaken for the present study indicate that there is relatively little acknowledgement of the critical roles played by pollinators and pollination. This, however, highlights the large opportunities that exist to increase decision-makers' awareness of pollinator-related issues.

FAO has supported countries with the development of their NBSAPs (e.g. in Ethiopia)[47] and could assist them with the updating of their NBSAPs. This could include providing technical guidance to countries, at their request, on how to improve the coverage of pollinators and pollination in their NBSAPs. This support would strengthen the collaboration between FAO and the CBD on invertebrate pollinators.

## 5.2 Invertebrate pollinators in the work of FAO and the Commission

The Conference of the Parties to the CBD's decision 14/6 invites FAO to facilitate the implementation of the International Pollinator Initiative's Plan of Action 2018–2030 and to collaborate in the development of guidance and technical advice to countries in areas such as the use of chemicals in agriculture, protection programmes for native pollinators in natural ecosystems, promotion of biodiverse production systems, crop rotation, monitoring of native pollinators and environmental education.

As important components of "associated biodiversity", pollinators are covered by the *Framework for Action on Biodiversity for Food and Agriculture* (FAO, 2022), which also refers specifically to the implementation of the International Pollinator Initiative.

As the objectives of the Commission's Work Plan for the Sustainable Use and Conservation of Micro-organism and Invertebrate Genetic Resources for Food and Agriculture align with those of the International Pollinator Initiative, which as noted above is facilitated by FAO, there are opportunities for the Commission and its Members to contribute to initiative at both international and national levels. There is a need to ensure that FAO and the Commission's work on pollinators is aligned and in synergy with the International Pollinator Initiative.

All activities related to the topic of invertebrate pollinators undertaken under the Commission's work plan could be regularly reported to the International Pollinator Initiative in order to help build synergies (and avoid duplication of efforts) in national projects and research up to 2030.

The following paragraphs describe ways in which the Commission and its members could potentially contribute to each of the objectives of the operation objectives of the Plan of Action 2018–2030.

***Objective 1***: *Implementing coherent and comprehensive policies for the conservation and sustainable use of pollinators at the local, subnational, national, regional and global levels, and promoting their integration into sectoral and cross-sectoral plans, programmes and strategies.*

The establishment and implementation of policies such as national pollinator strategies and NBSAPs are opportunities for Commission Members to take action on pollinators. Reference to pollinators could also be considered in the development or revision of national strategies for the implementation of the Commission's global plans of action.

***Objective 2***: *Reinforcing and implementing management practices that maintain healthy pollinator communities, and enable farmers, beekeepers, foresters, land managers and urban communities to harness the benefits of pollination for their productivity and livelihoods.*

Indigenous Peoples and local communities and their knowledge can be a source of solutions to challenges in pollinator management, as illustrated in recently published literature on biocultural approaches to pollinator conservation (Hill *et al.*, 2019; Hill *et al.*, 2020). Knowledge co-produced through inclusive, participatory processes that involve many groups of stakeholders, including Indigenous Peoples and local communities, can result in better, more acceptable and more meaningful solutions tailored for each local context. The future work of FAO and the Commission on pollinator-related activities and initiatives should therefore continue to acknowledge Indigenous Peoples and deliberately include their participation in decision-making.

[47] https://www.thegef.org/project/support-somalia-development-its-first-nbsap-and-fifth-national-report-cbd

Similarly, the Plan of Action 2018–2030 targets the development of tools and guidance at national, regional and global levels. The Commission and its Members could promote and encourage the use of this guidance and these tools (e.g. the Pesticide Registration Toolkit) at national level.

***Objective 3***: *Promoting education and awareness in the public and private sectors of the multiple values of pollinators and their habitats, in improving the tools for decision-making, and in providing practical actions to reduce and prevent pollinator decline.*

With regard to the International Pollinator Initiative's objective of promoting education and public awareness of the value of pollinators and their habitats, improving tools for decision-making and providing practical actions to reduce and prevent pollinator decline, the Commission could amplify and leverage work on awareness raising and capacity development through existing channels at different levels.

FAO's work under the first Plan of Action of the International Pollinator Initiative resulted in many knowledge products (see Annex I) and FAO will continue collaborating in the development of codes, protocols, technical guidance and tools to support pollinator conservation under the Plan of Action 2018–2030. A list of current FAO activities that contribute to the implementation of the International Pollinator Initiative was presented to the CBD COP 15 (CBD/COP/15/INF/24).[48] The Commission could amplify and leverage work on awareness raising and capacity development through various existing channels at various levels.

***Objective 4***: *Monitoring and assessing the status and trends of pollinators, pollination and habitats in all regions and to address gaps in knowledge, including by fostering relevant research.*

Opportunities exist to strengthen collaboration and cooperation between organizations and institutions on the monitoring and reporting of pollinator-related data and activities. Future assessments of invertebrate pollinators could give a more complete reporting of status and trends, management options, risks and drivers if they include different knowledge systems – especially indigenous and local knowledge.

FAO in its work facilitating and implementing the International Pollinator Initiative could promote the implementation of standardized monitoring approaches such as the EU Pollinator Monitoring Scheme in regions that lack baseline data on pollinators, as this would enable direct comparisons of pollinator data that could be useful for decision-makers. This would build on the FAO's previous work on the monitoring of pollinator populations.

Research on invertebrate pollinators that helps to close the knowledge gap identified above could be facilitated by the Commission and its Members. As noted by Dicks *et al.* (2016), governments could fund participatory research on improving yields in organic, diversified and ecologically intensified farming – an area that is currently not strongly supported.

[48] https://www.cbd.int/doc/c/d8be/e5af/ff0b5fe9783da03305fbff1a/cop-15-inf-23-en.pdf

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# Annex I. Knowledge products developed during the first International Pollinator Initiative and the Plan of Action 2000-2015

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2 FAO. 2009. *Tool for Valuation of Pollination Services at a National Level*. Rome. https://www.fao.org/sustainable-food-value-chains/training-and-learning-center/details-materials/en/c/328058/

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4 FAO. 2011. *Potential Effects of Climate Change on Crop Pollination. Rome*. www.fao.org/docrep/014/i2242e/i2242e00.htm

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14 FAO. 2016. *Mainstreaming Ecosystem Services and Biodiversity into Agricultural Production and Management in the Pacific Islands*. Rome. www.fao.org/3/a-i6505e.pdf

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# Annex II. Overview of strategic responses to risks and opportunities associated with pollinators and pollination from the summary for policymakers of the Intergovernmental Science-Policy Platform (IPBES) *Assessment report on pollinators, pollination and food production* (IPBES, 2016)

**Overview of strategic responses to risks and opportunities associated with pollinators and pollination**. Examples of specific responses are provided, selected from Chapters 5 and 6 of the assessment report to illustrate the scope of each proposed strategy. This is not a comprehensive list of available responses and represents around half of the available options covered in the assessment report. Not all the responses shown for "improving current conditions" will benefit pollinators in the long term, and those with potential adverse, as well as positive, effects are marked with an asterisk. All the responses from Chapter 6 that are already being implemented somewhere in the world and have well-established evidence of direct (rather than assumed or indirect) benefits to pollinators are included in the table and highlighted in bold.

| Ambition | Strategy | Examples of responses | Chapter references |
|---|---|---|---|
| Improving current conditions for pollinators and/ or maintaining pollination | Manage immediate risks | • **Create uncultivated patches of vegetation such as field margins with extended flowering periods** | **2.2.1.1, 2.2.1.2, 2.2.2.1.1, 2.2.2.1.4, 6.4.1.1.1, 5.2.7.5, 5.2.7.7, 5.3.4** |
| | | • Manage blooming of mass-flowering crops* | 2.2.2.1.8, 2.2.3, 6.4.1.1.3 |
| | | • Change management of grasslands | 2.2.2.2, 2.2.3, 6.4.1.1.7 |
| | | • **Reward farmers for pollinator-friendly practices** | 6.4.1.3, 5.3.4 |
| | | • Inform farmers about pollination requirements | 5.4.2.7, 2.3.1.1, 6.4.1.5 |
| | | • Raise standards of pesticide and genetically-modified organism risk assessment | 2.3.1.2, 2.3.1.3, 6.4.2.1.1, 6.4.2.2.5 |
| | | • Develop and promote the use of technologies that reduce pesticide drift and agricultural practices that reduce exposure to pesticides | 2.3.1.2, 2.3.1.3, 6.4.2.1.3, 6.4.2.1.2 |
| | | • Prevent infections and treat diseases of managed pollinators; regulate trade in managed pollinators | 2.4, 6.4.4.1.1.2.2, 6.4.4.1.1.2.3, 6.4.4.2 |

| Ambition | Strategy | Examples of responses | Chapter references |
| --- | --- | --- | --- |
| Improving current conditions for pollinators and/ or maintaining pollination | Manage immediate risks | • Reduce pesticide use (includes integrated pest management) | 6.4.2.1.4 |
| | Utilize immediate opportunities | • Support product certification and livelihood approaches | 5.4.6.1, 6.4.1.3 |
| | | • **Improve managed bee husbandry** | 2.4.2, 4.4.1.1, 5.3.5, 6.4.4.1.3 |
| | | • Develop alternative managed pollinators* | 2.4.2 |
| | | • Quantify the benefits of managed pollinators | 6.4.1.3, 6.4.4.3 |
| | | • Manage road verges* | 2.2.2.2.1, 6.4.5.1.4, 6.4.5.1.6 |
| | | • Manage rights of way and vacant land in cities to support pollinators | 2.2.2.3, 6.4.5.1.4, 6.4.5.1.6, 6.4.5.4 |
| Transforming agricultural landscapes | Ecologically intensify agriculture through active management of ecosystem services | • **Support diversified farming systems** | 2.2.1.1, 2.2.1.2, 2.2.2.1.1, 2.2.2.1.6, 5.2.8, 5.4.4.1, 6.4.1.1.8 |
| | | • Promote no-till agriculture | 2.2.2.1.3, 6.4.1.1.5 |
| | | • Adapt farming to climate change | 2.7.1, 6.4.1.1.12 |
| | | • Encourage farmers to work together to plan landscapes; engage communities (participatory management) | 5.2.7, 5.4.5.2, 6.4.1.4 |
| | | • Promote integrated pest management | 2.2.2.1.1, 2.3.1.1, 6.4.2.1.4, 6.4.2.2.8, 6.4.2.4.2 |
| | | • Monitor and evaluate pollination on farms | 5.2.7, 6.4.1.1.10 |
| | | • Establish payment for pollination services schemes | 6.4.3.3 |
| | | • Develop and build markets for alternative managed pollinators | 6.4.4.1.3, 6.4.4.3 |
| | | • Support traditional practices for managing habitat patchiness, crop rotation and co-production of knowledge between indigenous and local knowledge holders, scientists and stakeholders | 2.2.2.1.1, 2.2.3, 5.2.7, 5.4.7.3, 6.4.6.3.3 |

| Ambition | Strategy | Examples of responses | Chapter references |
|---|---|---|---|
| Transforming agricultural landscapes | Strengthen existing diversified farming systems | • **Support organic farming systems; diversified farming systems; and food security,** including the ability to determine one's own agricultural and food policies, resilience and ecological intensification | 2.2.2.1.1, 2.2.2.1.6, 5.2.8, 5.4.4.1, 6.4.1.1.4, 6.4.1.1.8 |
| | | • Support "biocultural diversity" conservation approaches through recognition of rights, tenure and strengthening of indigenous and local knowledge and traditional governance that supports pollinators | 5.4.5.3, 5.4.5.4, 5.4.7.2, 5.4.7.3 |
| | Invest in ecological infrastructure | • **Restore natural habitats** (also in urban areas) | 6.4.3.1.1, 6.4.5.1.1, 6.4.5.1.2 |
| | | • Protect heritage sites and practices | 5.2.6, 5.2.7, 5.3.2, 5.4.5.1, 5.4.5.3 |
| | | • Increase connectivity between habitat patches | 2.2.1.2, 6.4.3.1.2 |
| | | • Support large-scale land-use planning and traditional practices that manage habitat patchiness and "biocultural diversity" | 5.1.3, 5.2.6, 5.2.7, 5.2.9, 6.4.6.2.1 |
| Transforming society's relationship with nature | Integrate peoples' diverse knowledge and values into management | • Translate pollinator research into agricultural practices | 2.2.1, 2.2.2, 2.2.3, 2.2.1.2, 6.4.1.5, 6.4.4.5 |
| | | • Support knowledge co-production and exchange among indigenous and local knowledge holders, scientists and stakeholders | 5.4.7.3, 6.4.1.5, 6.4.6.3.3 |
| | | • Strengthen indigenous and local knowledge that fosters pollinators and pollination, and knowledge exchange among researchers and stakeholders | 5.2.7, 5.4.7.1, 5.4.7.3, 6.4.4.5, 6.4.6.3.3 |
| | | • Support innovative pollinator activities that engage stakeholders with attachments to the multiple socio-cultural values of pollinators | 5.2.3, 5.3.2, 5.3.3, 5.3.4, 5.4.7.1, 6.4.4.5 |
| | Link people and pollinators through collaborative, cross sectoral approaches | • Monitor pollinators (collaboration between farmers, the broader community and pollinator experts) | 5.2.4, 5.4.7.3, 6.4.1.1.10, 6.4.4.5, 6.4.6.3.4 |
| | | • Increase taxonomic expertise through education, training and technology | 6.4.3.5 |
| | | • Education and outreach programmes | 5.2.4, 6.4.6.3.1 |
| | | • Manage urban spaces for pollinators and collaborative pathways | 6.4.5.1.3 |
| | | • Support high-level pollination initiatives and strategies | 5.4.7.4, 6.4.1.1.10, 6.4.6.2.2 |

# Annex III. Questionnaire of existing initiatives, policies and instruments for the sustainable use and conservation of pollinators

1. First name *:
2. Last name *:
3. Position/Title:
4. Affiliation:
5. Email *:
6. Project/focal person (first name,last name) (if different from respondent):
7. Main type of pollinator-related activity*: Initiative, project, programme, network, committee, listserv or other virtual sharing platform, policy, legal instrument or regulation, assessment, report, research, other (specify - open)
8. Title of activity*: enter in open field
9. Lead organization/institution or authority (for policy or legal instrument) (for example, Government of country )*: enter in open field
10. Other organizations or institutions involved: enter in open field
11. Time / duration of activity (i.e. number of months or years)
12. Time period (Start Date/Year and End Date/Year)
13. Website/URL*: enter in open field [extra fields for more URLs if needed]
14. Additional references/Supporting material
15. Objective of the pollinator-related activity referred to above [can check more than one]
    - Technical work on pollinators: (dropdown options: Characterization, conservation, breeding, protection, monitoring, data/indicator)
    - Knowledge generation and management about pollinators/pollination: (dropdown options: awareness raising, research, education/learning, capacity-building, knowledge/information sharing, networking)m
    - Enabling environment for pollinators: (dropdown options: regulation, policy, mainstreaming)
    - other (specify - open)
16. Additional description: enter in open field (maximum 500 words)
17. Supporting information (permissible formats: gif, jpg, jpeg, png, pdf, mov, mp3.): upload
18. Is it ok to contact you by email in the case we need clarification on the submission? yes/no
19. Is it ok to contact you by phone in the case we need clarification on the submission? yes/no
20. Would you like to receive a copy of your responses to the email address indicated above? Yes/no

* indicates the question requires an answer to successfully submit the form

# Annex IV. Output results by country of policies, legislations and regulations (instruments) searched within the FAOLEX database

| Country or region | Number of instruments |
|---|---|
| Albania | 3 |
| Algeria | 1 |
| American Samoa | 1 |
| Andean Community | 1 |
| Andorra | 1 |
| Angola | 7 |
| Angola; Hungary | 1 |
| Argentina | 44 |
| Armenia | 1 |
| Armenia; Belarus; Kazakhstan; Kyrgyzstan; Russian Federation | 1 |
| Australia | 32 |
| Austria | 17 |
| Azerbaijan | 8 |
| Azerbaijan; Bulgaria | 1 |
| Bahamas | 3 |
| Bahrain | 1 |
| Bangladesh | 3 |
| Belarus | 18 |
| Belarus; Bulgaria | 1 |
| Belgium | 22 |
| Belize | 1 |
| Bermuda | 3 |
| Bhutan | 1 |
| Bolivia (Plurinational State of) | 6 |

| Country or region | Number of instruments |
|---|---|
| Bosnia and Herzegovina | 17 |
| Botswana | 15 |
| Brazil | 43 |
| British Virgin Islands | 1 |
| Bulgaria | 8 |
| Burkina Faso | 3 |
| Burundi | 5 |
| Cameroon | 1 |
| Canada | 56 |
| Central African Republic | 1 |
| Chad | 3 |
| Chile | 20 |
| China | 3 |
| Colombia | 4 |
| Congo | 1 |
| Costa Rica | 12 |
| Côte d’Ivoire | 1 |
| Croatia | 55 |
| Cuba | 3 |
| Czechia | 20 |
| Denmark | 13 |
| Democratic People’s Republic of Korea | 1 |
| Democratic Republic of the Congo | 1 |
| Dominican Republic | 3 |
| Ecuador | 15 |
| Egypt | 5 |
| El Salvador | 8 |
| Estonia | 3 |
| Eswatini | 3 |

| Country or region | Number of instruments |
|---|---|
| Ethiopia | 5 |
| European Union | 53 |
| Fiji | 1 |
| Finland | 6 |
| France | 12 |
| French Polynesia | 1 |
| Georgia | 13 |
| Germany | 25 |
| Ghana | 2 |
| Gibraltar | 1 |
| Greece | 17 |
| Greece; Georgia | 1 |
| Greece; Morocco | 1 |
| Greenland | 1 |
| Grenada | 2 |
| Guatemala | 3 |
| Guernsey | 1 |
| Guyana | 2 |
| Haiti | 3 |
| Honduras | 7 |
| Hungary | 10 |
| India | 8 |
| Iran (Islamic Republic of) | 3 |
| Iraq | 1 |
| Ireland | 17 |
| Israel | 4 |
| Italy | 64 |
| Italy; Switzerland | 1 |
| Jamaica | 13 |

| Country or region | Number of instruments |
|---|---|
| Jersey | 7 |
| Jordan | 8 |
| Jordan; Syrian Arab Republic | 1 |
| Kazakhstan | 10 |
| Kazakhstan; China | 1 |
| Kazakhstan; China; Kyrgyzstan; Russian Federation; Tajikistan; Uzbekistan | 1 |
| Kenya | 10 |
| Korea, Republic of | 1 |
| Kuwait | 1 |
| Kyrgyzstan | 10 |
| Lao People's Democratic Republic | 1 |
| Latvia | 2 |
| Lebanon | 5 |
| Lebanon; Yemen | 1 |
| Lesotho | 1 |
| Liberia | 1 |
| Libya | 3 |
| Liechtenstein | 4 |
| Luxembourg | 7 |
| Madagascar | 14 |
| Malawi | 6 |
| Malaysia | 1 |
| Mali | 5 |
| Malta | 8 |
| Mauritania | 2 |
| Mauritius | 1 |
| MERCOSUR | 4 |
| Mexico | 54 |

| Country or region | Number of instruments |
|---|---|
| Micronesia (Federated States of) | 1 |
| Mongolia | 1 |
| Montenegro | 13 |
| Morocco | 13 |
| Namibia | 4 |
| New Caledonia | 1 |
| New Zealand | 8 |
| Nicaragua | 4 |
| Niger | 3 |
| Nigeria | 4 |
| Norfolk Island | 1 |
| North Macedonia | 18 |
| Norway | 15 |
| Oman | 6 |
| Pakistan | 3 |
| Palestinian Authority | 6 |
| Panama | 5 |
| Paraguay | 4 |
| Peru | 19 |
| Pitcairn | 1 |
| Poland | 22 |
| Portugal | 26 |
| Puerto Rico | 2 |
| Qatar | 1 |
| Republic of Moldova | 6 |
| Russian Federation | 89 |
| Russian Federation; Armenia; Belarus; Kazakhstan; Kyrgyzstan; Republic of Moldova; Tajikistan; Turkmenistan; Uzbekistan; Ukraine | 1 |
| Rwanda | 7 |

| Country or region | Number of instruments |
| --- | --- |
| Saint Helena, Ascension and Tristan da Cunha | 3 |
| Saint Vincent and the Grenadines | 1 |
| San Marino | 1 |
| Senegal | 1 |
| Serbia | 32 |
| Serbia and Montenegro | 1 |
| Serbia and Montenegro; Belarus | 1 |
| Seychelles | 1 |
| Slovakia | 17 |
| Slovenia | 21 |
| Solomon Islands | 1 |
| Somalia | 1 |
| South Africa | 11 |
| South Sudan | 1 |
| Spain | 19 |
| Sri Lanka | 3 |
| Svalbard | 1 |
| Sweden | 5 |
| Switzerland | 25 |
| Syrian Arab Republic | 12 |
| Tajikistan | 12 |
| Thailand | 5 |
| Timor-Leste | 1 |
| Trinidad and Tobago | 2 |
| Tunisia | 1 |
| Türkiye | 41 |
| Türkiye; Ukraine | 1 |
| Turkmenistan | 3 |
| Tuvalu | 1 |

| Country or region | Number of instruments |
|---|---|
| Uganda | 2 |
| Ukraine | 16 |
| Ukraine; China | 1 |
| United Arab Emirates | 6 |
| United Republic of Tanzania | 11 |
| United Kingdom of Great Britain and Northern Ireland | 26 |
| United States of America | 12 |
| Uruguay | 15 |
| Uzbekistan | 18 |
| Uzbekistan; Bulgaria | 1 |
| Uzbekistan; Georgia | 1 |
| Uzbekistan; Republic of Moldova | 1 |
| Viet Nam | 2 |
| Yemen | 3 |
| Zambia | 1 |
| Zimbabwe | 6 |

*One Guide for Control on Imported Foods of the Cooperation Council for the Arab States of the Gulf .

# Annex V. Glossary

**These definitions are taken from IPBES 2016; Garibaldi et al., 2019 and the World Organisation for Animal Health (WOAH, formerly the Office International des Epizooties, OIE) (https://www.oie.int/en/disease/diseases-of-bees) with minimal editing for stylistic consistency.**

### Agricultural intensification

The process by which land becomes increasingly used for agricultural production. Agricultural intensification can apply to high-input (machinery, fuel, chemicals) farming as well as to lower-input traditional to organic practices.

### Agroecology

The science and practice of applying ecological concepts, principles and knowledge (i.e. the interactions of, and explanations for, the diversity, abundance and activities of organisms) to the study, design and management of sustainable agroecosystems. It includes the roles of human beings as a central organism in agroecology by way of social and economic processes in farming systems. Agroecology examines the roles and interactions among all relevant biophysical, technical and socioeconomic components of farming systems and their surrounding landscapes.

### Alien species

A species, subspecies, or lower taxon occurring outside its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans); includes any part, gametes or propagule of such a species that might survive and subsequently reproduce. Also known as non-native, non-indigenous, foreign or exotic species.

### American foulbrood

A serious disease of honey bees caused by a spore forming bacteria called Paenibacillus larvae. It occurs throughout the world. The bacteria kill the larvae in the brood cell. In infected hives the colony has a mottled look due to empty cells, there may be a typical smell, and the brood is slimy or slurpy. American foulbrood is spread by bacterial spores formed in infected larvae, which are very resistant and survive many years. The spores spread the disease by transfer of wax, queens or contaminated honey or via exchange of combs. Diagnosis is confirmed by identifying the bacteria by molecular means, by culture or by microscopy. Treatment with antibiotics will destroy the vegetative bacteria but does not kill the spores, so the disease will recur. Therefore, it is often recommended to burn the hive and equipment, as this may be the only way to destroy the spores.

### Beekeeping (apiculture)

The husbandry of bees, especially honey bees (the genus Apis) but can be applied to other bees (see "Managed pollinators").

### Bumble bee

Members of the bee genus Bombus: social bees that form colonies with a single queen or brood-parasitic or cuckoo bumble-bees (previously Psithyrus). Currently 262 species are known: found primarily in higher latitudes and at higher altitudes in the Northern Hemisphere, although they also occur in South America and New Zealand (where they were introduced).

### Conventional intensification

Has led to larger fields of monoculture crops that rely on external inputs, including synthetic fertilizers and pesticides. However, many farming systems exist that do not conform to this trend and have different ecological, social and economic performance. These include traditional farming approaches and others that integrate novel technologies. Given that these alternative approaches have different histories, the terms that people use to classify them overlap.

### Diversified farming

Farms that integrate several crops and (or) animals in the production system. A diversified farming system is a newer concept, emphasizing a suite of farming practices that promote agrobiodiversity across scales, regenerating ecosystem services and reducing the need for external inputs. This concept is closely allied with "agroecology" and "ecological intensification", while emphasizing cross-scale diversification as the mechanism for sustainable production.

### Ecological intensification

Describes a process rather than an end point. It provides one path towards higher crop yield that fits within the original sense of sustainable intensification. Ecological intensification emphasizes management that enhances ecological processes that support production, including biotic pest regulation, nutrient cycling and pollination; there is an explicit focus on conserving and using functional biodiversity. The result is a farm that is likely to meet the definition of a diversified farming system.

### Ecosystem

A community of living organisms (plants, animals, fungi and various microbes) in conjunction with the non-living components of their environment (such as energy, air, water and mineral soil), all interacting as a system.

### Ecosystem functioning

The flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem. It includes many processes, such as biomass production, trophic transfer through plants and animals, nutrient cycling, water dynamics and heat transfer. The concept is used here in the broad sense and can thus be taken as being synonymous with ecosystem properties or ecosystem structure and function.

### Ecosystem service

A service that is provided by an ecosystem as an intrinsic property of its functionality (e.g. pollination, nutrient cycling, nitrogen fixation, fruit and seed dispersal). The benefits (and occasionally disbenefits) that people obtain from ecosystems. These include provisioning services, such as food and water; regulating services, such as flood and disease control; and cultural services, such as recreation and sense of place. In the original definition of the Millennium Ecosystem Assessment the concept of "ecosystem goods and services" is synonymous with ecosystem services.

### Farm

An area of land, a holding of any size from a small plot or garden (fractions of a hectare) to several thousand hectares that is devoted primarily to agriculture to produce food, fibre or fuel. A farm may be owned and operated by an individual, a family, a community, a corporation or a company, and may produce anywhere from one to many types of produce or animal.

### Field

(In agriculture) a defined area of cleared enclosed land used for cultivation or pasture.

### Flower strips

Linear areas of land within or at the edges of fields, farms or other areas (rights of way, riparian areas, etc.) where flowering plants are seeded and encouraged to grow, often for the benefit of pollinators and other wildlife.

### Flower-visitor

An animal that visits flowers (a.k.a. anthophile) but is not necessarily a pollinator.

### Fungicide

A substance that kills or inhibits the growth and development of fungi. Fungicides may be synthetic chemicals, natural chemicals or biological agents.

### Generalist species

A species able to thrive in a wide variety of environmental conditions and that can make use of a variety of different resources (e.g. a flower-visiting insect that lives on the floral resources provided by several or many different plants).

### Habitat connectivity

The degree to which the landscape facilitates the movement of organisms (animals, plant reproductive structures, pollen, pollinators, spores, etc.) and other environmentally important resources (e.g. nutrients and moisture) between similar habitats. Connectivity is hampered by fragmentation (q.v.).

### Habitat degradation

A general term describing the set of processes by which habitat quality is reduced. Habitat degradation may occur through natural processes (e.g. drought, heat, cold) and through human activities (forestry, agriculture, urbanization).

### Habitat fragmentation

A general term describing the set of processes by which habitat loss results in the division of continuous habitats into a greater number of smaller patches of lesser total size and isolated from each other by a matrix of dissimilar habitats. Habitat fragmentation may occur through natural processes (e.g. forest and grassland fires, flooding) and through human activities (forestry, agriculture, urbanization).

### Hedgerow

A row of shrubs or trees that forms the boundary of an area such as a garden, field, farm, road or right of way.

### Herbicide

A substance that kills or inhibits the germination, growth and development of plants. Herbicides may be synthetic chemicals, natural chemicals or biological agents.

**Invasive alien species**

An alien species that becomes established in natural or semi-natural ecosystems or habitat, is an agent of change and threatens native biological diversity.

**Invasive species**

A species that, once it has been introduced outside its native distributional range, has a tendency to spread over space without direct human assistance.

**Managed pollinator**

A pollinator that is maintained by human beings through husbandry (e.g. some honey bees, some leafcutting and orchard bees, some bumble bees). The definition can be broadened to include wild pollinators (q.v.) that flourish by human encouragement.

**Monoculture**

The cultivation or growth of only one agricultural product in a given area (field, farm, garden, forest).

**Native pollinator**

A pollinator species living in an area where it evolved or dispersed without human intervention.

**Organic farming**

Originated as a holistic system for enhancing soil fertility, water storage and the biological control of crop pests and diseases, and was traditionally associated with low-input, small-scale, diversified farms. A more recent development, certified organic farming, prohibits the use of most synthetic inputs and genetically modified organisms while allowing organic fertilizers and pesticides. Many organic farms today practice “input substitution”, and so – similar to conventional farms – they are high input, occur on a large scale and sustain low-crop and non-crop diversity but use permitted organic products instead of synthetic fertilizers and pesticides. Thus, today, organic agriculture includes a wide spectrum of farming styles.

**Parasite**

An organism that lives on or within another organism of a different species (the host), from which it obtains nourishment and to which it causes harm.

**Pest**

An animal, plant, fungus or other organism that thrives in places where it is not wanted by people, for example in fields, with livestock, in forests or in gardens.

**Pesticide**

A substance that kills pests (q.v.). Pesticides may be synthetic chemicals, natural chemicals or biological agents.

**Plant–pollinator network**

A group of local plant and pollinator species and the links among them that establish which interacts with which (qualitative network). A network can also include a measure of the strength of each individual interaction link (quantitative network).

### Pollination

The transfer of pollen from an anther to a stigma. Pollination may occur within flowers of the same plant, between flowers of the same plant or between flowers of different plants (or combinations thereof).

### Pollinator

An agent that transports pollen. Such agents may be animals of many kinds or physical (wind or water), or both.

### Pollinator decline

Decrease in abundance or diversity, or both, of pollinators.

### Pollinator dependence

The degree to which either seed or fruit production, or both, of a plant declines in the total absence of animal pollinators.

### Polyculture

The simultaneous cultivation or growth of two or more compatible agricultural products (e.g. intercropping, crops and livestock, agroforestry, crops and aquaculture).

### Small hive beetle infestation

The small hive beetle, Aethina tumida, is a scavenger and parasite of honey-bee colonies. It is native to Africa but was introduced to the United States of America, Egypt, Canada and Australia by commercial movement of bees. Considered a minor pest in its home range, it has become a major problem in introduced areas. Both adult and larval beetles feed on larvae, pollen, honey and bee brood. The adult female lays her eggs in the hive. The larvae hatch and feed on brood, pollen and honey then leave the hive to pupate in the soil, where the adults hatch then fly to look for new hives. Spread can therefore be rapid, as the adults have a range of several kilometres. When infestation is heavy, the bees may desert the hive.

### Solitary bees

Bees that are not fully social (such as honey bees [q.v.], bumble bees [q.v.] and stingless bees [q.v.]) but are instead solitary or primitively social. There are more than 19 000 species of solitary bee.

### Specialist species

A species that can thrive only in restricted environmental conditions and can make use of only a few different (even only one) resources (e.g. a flower-visiting insect that lives on the floral resources provided by one plant or a few different plants, or a plant that depends on just one or a few animal species for pollination).

### Stingless bees

A large group of social bees (about 500 species), comprising the tribe Meliponini, characterized by a highly reduced stinger that cannot be used for defence. Stingless bees belong in the family Apidae and are related to common honey bees, carpenter bees, orchid bees and bumble bees.

### Sustainable intensification

Was originally defined as increasing crop yield while improving ecological and social conditions. It relied on sustainable practices, such as agroforestry, conservation agriculture, and biological pest control, to establish low-input "resource-conserving systems" based on promoting favourable ecological interactions within the agroecosystem rather than depending on external inputs. These approaches were found to improve yields and livelihoods in developing countries. However, recent usage has shifted the focus towards capital- and external-input intensive means of enhancing resource-use efficiencies, such as irrigation, precision agriculture, fertilizer application and genetically modified organisms, leading to criticism that the concept no longer promotes social equity.

### Tropilaelaps

There are several species of Tropilaelaps mites, notably Tropilaelaps clareae and T. koenigerum. Each species has a different geographic range, but they are all found in Asia. These mites are external parasites that feed on brood (bee larva and pupae) and cause an irregular pattern of sealed and unsealed brood as well as deformities in adults. They spread by direct contact from bee to bee or by movement of brood.

### Urbanization

The process by which villages, towns, cities and other built-up areas grow or by which societies become more urban.

### Varroosis

Varroosis is caused by a mite, an external parasite of adults and brood. There are four species of Varroa mite, but Varroa destructor is the most important. They are found throughout the world except for Australia and the south island of New Zealand. They are known to spread a virus that causes deformed wing disease. Adult bees affected with varroosis also have shrunken abdomens. Early signs of infection normally go unnoticed, and only when infection is heavy does it become apparent, with adult mites seen on bees. The infection spreads by direct contact from adult bee to adult bee and by the movement of infested bees and bee brood. The mite can also act as a vector for viruses of the honey bee.

### Weed

A plant that is a pest (q.v.) in a particular circumstance.

### Wild pollinator

A pollinator that can live without human husbandry. Some may depend on agricultural settings for survival.

ISBN 978-92-5-137943-1

CC6499EN/1/06.23