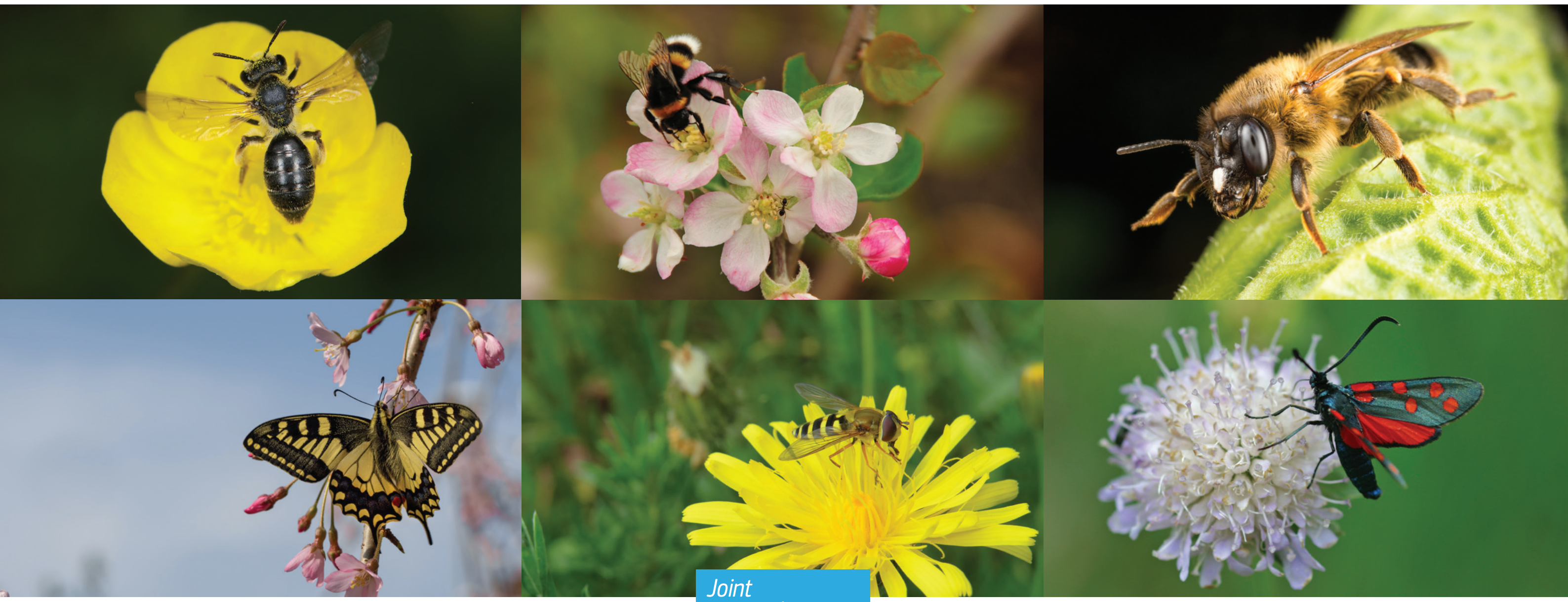
European Commission

JRC TECHNICAL REPORT

Proposal for an EU Pollinator Monitoring Scheme

Simon G. Potts, Jens Dauber, Axel Hochkirch, Bas Oteman, David B. Roy, Karin Ahrné, Koos Biesmeijer, Tom D. Breeze, Claire Carvell, Catarina Ferreira, Úna FitzPatrick, Nick J.B. Isaac, Mikko Kuussaari, Toshko Ljubomirov, Joachim Maes, Hien Ngo, Adara Pardo, Chiara Polce, Marino Quaranta, Josef Settele, Martin Sorg, Constanti Stefanescu, Ante Vujić

2021



Joint Research Centre

EUR 30416 EN

Contact information

Name: Joachim Maes

Email: joachim.maes@ec.europa.eu

EU Science Hub

https://ec.europa.eu/jrc

JRC 122225

EUR 30416 EN

PDF ISBN 978-92-76-23859-1 ISSN 1831-9424 doi:10.2760/881843

Luxembourg: Publications Office of the European Union, 2021

How to cite this report: Potts, S.G., Dauber, J., Hochkirch, A., Oteman, B., Roy, D.B., Ahrné, K., Biesmeijer, K., Breeze, T.D., Carvell, C., Ferreira, C., FitzPatrick, Ú., Isaac, N.J.B., Kuussaari, M., Ljubomirov, T., Maes, J., Ngo, H., Pardo, A., Polce, C., Quaranta, M., Settele, J., Sorg, M., Stefanescu, C., Vujić, A., Proposal for an EU Pollinator Monitoring Scheme, EUR 30416 EN, Publications Office of the European Union, Ispra, 2021, ISBN 978-92-76-23859-1, doi:10.2760/881843, JRC122225.

Foreword

Now, more than ever, society has recognised the critical importance of pollinators and pollination – for global food and health security, good quality of life and ecosystem functioning. However, we also know that pollinators face unprecedented threats from human activities, including land-use change, intensive agricultural practices and pesticide use, pollution, invasive alien species, pathogens, and increasingly - climate change. A set of policy options was clearly presented by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) in its assessment report on pollinators, pollination and food production released in 2016.

The IPBES pollination assessment report has provided the most complete picture of the status and trends of pollinators to date and highlighted critical gaps in knowledge which could hinder the implementation of effective policy responses needed to support pollinators – the vast majority of which are wild.

The decline in wild pollinator occurrence, abundance and diversity is a matter of international concern because pollinators such as bees and butterflies know no borders. The conservation of pollinators and the many contributions to people provided by pollination enrich the lives of all of us everywhere. Strategic policy responses which aim to improve conditions for pollinators, transform agricultural landscapes and ultimately reshape our relationship with nature are clearly enhanced by harmonised international and regional cooperation. This is even more indispensable when it comes to filling critical gaps in knowledge and data.

This timely proposal for a EU Pollinator Monitoring Scheme comes on the heels of a July 2020 report by the European Court of Auditors (ECA), which confirmed that the decline of pollinators in Europe is a major threat to the environment, agriculture and food supply for Europe – and that initiatives to support wild pollinators require appropriate monitoring mechanisms in order to bear fruit.

This proposal to complement the EU Pollinators Initiative and EU Biodiversity Strategy highlights the critical role of credible science and data for designing and implementing effective policies which address the dual crises of biodiversity loss and climate change. The IPBES Global Assessment recently found that one million plant and animal species are currently threatened with extinction. This heightens the need for schemes such as this to systematically monitor the status and trends of pollinators and so provide us with the kind of evidence-informed decision-making necessary to achieve a sustainable future.

Ana María Hernández Salgar, Chair of IPBES

Acknowledgements

It has been a privilege to work closely with so many experts in the field of pollination, and to witness their commitment despite this period of great global uncertainty caused by the COVID-19 pandemic.

We are also grateful to many individuals who provided their input at various stages of this project.

For replying so positively to our call for data offers, we thank: András Báldi, Mario Balzan, Aleksandar Ćetković, Andrea Holzschuh, David Kleijn, Ana Montero, Marino Quaranta, Pierre Rasmont and Denis Michez, Jane Stout, Nicolas Vereecken.

For providing access to the data used to inform power analysis, network design and indicator tests, we acknowledge: Ignasi Bartomeus and Curro Molina (unpublished data, BeeFun); Claire Carvell (UKCEH BigBee, UK PoMS); William Kunin (unpublished data, AgriLand); Theodora Petanidou and Georgios Nakas (unpublished data, ongoing PhD study under SERAPIS); Ante Vujić and Marina Janković (unpublished data, ongoing PhD study); Oliver Schweiger and Mark Frenzel (data organised under TERENO); Bernard Vaissière (data collected under the Apiformes network in France, funded by Pollinis, and FlorAbeilles database), Nicolas Laarman (Pollinis), Clémentine Gombault (FlorAbeilles database); David Roy, for requesting approval to use BMS data held within eBMS partnership, and the following people who consented to the use of BMS data: Mikko Kuussaari (Finland BMS), Liam Lysaght (Ireland BMS), Ian Middlebrook (UK BMS), Josef Settele (Germany BMS), Chris van Swaay (Netherlands BMS), Constanti Stefanescu (Catalonia BMS). Although only data from a subset of Butterfly Monitoring Schemes was used in this report, we thank the full set of partners in the European Butterfly Monitoring Scheme (eBMS) who approved the use of their data for the power analysis and scheme design: the Natural Environment Research Council (acting through the UK Centre for Ecology & Hydrology; contact-David Roy), Butterfly Conservation UK (contact - Ian Middlebrook), Helmholtz-Zentrum für Umweltforschung GmbH-UFZ (contact-Josef Settele), De Vlinderstichting (contact – Chris van Swaay), Catalonia BMS (contact – Constanti Stefanescu), Finnish Environment Institute (SYKE; contact – Mikko Kuussaari), Butterfly Conservation Europe (BCE; contact – Chris van Swaay), Research Institute Nature and Forest (INBO; contact – Dirk Maes), Muséum National d'Histoire Naturelle (MNHN, CNRS-UPMC; ; contact-Benoît Fontaine), Lund University (contact-Lars Pettersson), National Biodiversity Data Centre (NBDC) Ireland (contact-Liam Lysaght), Luxembourg Institute of Science and Technology (LIST; contact – Xavier Mestdagh), ZERYNTHIA Association (contact – Yeray León), Facultad de Ciencias de la Universidad Autónoma de Madrid (contact – Miguel Munguira), Društvo za Proučevanje in Ohranjanje Metuljev Slovenije (contact – Rudi Verovnik), Hungarian Lepidoptera Monitoring Network as part of the Jozsef Szalkay Hungarian Lepidopterists' Society (contact - András Szabadfalvi), Zoolab Department of Life Sciences and Systems Biology University of Turin (contact-Simona Bonelli), and TAGIS - Centro de Conservacao des Borboletas de Portugal (contact – Eva Monteiro). We thank Reto Schmucki for providing data on behalf of the eBMS partnership, and for producing Figure 1.1. The eBMS and national schemes are indebted to all volunteers who contributed data to these schemes.

We are also grateful to many individuals who provided information on taxonomic capacity. For taxonomic capacity on hoverflies, we acknowledge: Helge Heimburg, Frank Van de Meutter, Zdravko Hubenov, André van Eck, Libor Mazánek, Hans Henrik Bruun, Rune Bygebjerg, Olavi Kurina, Gunilla Ståhls-Mäkelä, Cédric Vanappelghem, Axel Ssymank, Laura Likov, Sándor Tóth, Martin Speight, Daniele Sommaggio, Dagmāra Čakstiņa, Erikas Lutovinovas, Alexander Weigand, Martin Ebejer, Paul Gatt, Jeroen van Steenis, Wouter van Steenis, John Smit, Łukasz Mielczarek, Ana Rita Goncalves, Amalia Balasoiu, Libor Mazanek, Marteen De Groot, Antonio R. Ricarte Saber, M. Ángeles Marcos-García, and Francis Gilbert.

For taxonomic capacity on butterflies, we acknowledge: Helmut Höttinger, Dirk Maes, Philippe Goffart, Toshko Ljubomirov, Martina Sasic, Elli Tzirkalli, Alois Pavlíčko, Emil Bjerregård, Toomas Tammaru, Benoît Fontaine, Martin Wiemers, Vassiliki Kati, Zsolt Bálint, Liam Lysaght, Simona Bonelli, Kristaps Vilks, Dalius Dapkus, Roland Proess, Xavier Mestdagh, Louis F. Cassar, Chris van Swaay, Marcin Sielezniew, Patrícia Garcia Pereira, Mihai Stanescu, Henrik Kalivoda, Rudi Verovnik, Miguel López Munguira, Constanti Stefanescu, and Lars Pettersson (butterflies and survey methods).

For taxonomic capacity on wild bees, we acknowledge: Marika Mänd, Juho P.T. Paukkunen, Benoit Geslin, Michael Kuhlmann, Theodora Petanidou, Miklós Sárospataki, Anikó Kovács-Hostyánszki, Robert Paxton, Jane Stout, Jānis Gailis, Eduardas Budrys, Nico Schneider, Mario Balzan, Menno Reemer, Józef Banaszak, David Baldock, Alexandra Popa, Peter Sima, Andrej Gogala, Francisco Javier Ortiz Sanchez, Ignasi Bartomeus, Jordi Bosch Gras, and Stuart Roberts.

For cost data, we acknowledge: Claire Carvell, Tom Breeze, Axel Hochkirch; Alexandra-Maria Klein; Ingolf Steffan-Dewenter; Bas Oteman; David Kleijn; Úna FitzPatrick; Marino Quaranta; Karin Ahrné, Lars Petterson; Mikko Kuussaari; Mario Balzan; Menelaos Stavrinides; Theodora Petanidou; Aniko Kovacs-Hostyanszki; Adam Vanbergen; Marie-Pierre Chauzat; Marika Mand; Denis Michez, Nicolas Vereecken, Hajnalka Szentgyorgyi, Ignasi Bartomeus; Jordi Bosch, Giedrius Švitra, Xavier Mestdagh, Albert Scrieciu, and Eva Monteiro

The constructive comments we received on earlier drafts of this report contributed greatly to improving its quality. In particular, we acknowledge feedback from Vujadin Kovacevic (Directorate-General for Environment), Katarzyna Biala (European Environment Agency), Maria Luisa Paracchini (Joint Research Centre), Veronika Vysna (Eurostat), and other colleagues from the European Commission's departments in charge of the environment, agriculture and rural development, research and innovation, health and food safety.

We are especially grateful to three outstanding academics who thoroughly reviewed this report: Lynn Dicks, David Kleijn and William Kunin.

We also acknowledge those representatives from EU Member States who responded to our invitation to review the report and not only provided their comments, but also engaged actively during various phases of this process.

Finally, we thank all the photographers who donated the beautiful pictures that make the reading of this report so much pleasanter.

Authors

Simon G. Potts (University of Reading, UK), Jens Dauber (Thünen Institute, Germany), Axel Hochkirch (Trier University, Germany), Bas Oteman (Dutch Butterfly Conservation, Netherlands), David B. Roy (UK Centre for Ecology & Hydrology, UK), Karin Ahrné (Swedish University of Agricultural Sciences, Sweden), Koos Biesmeijer (Naturalis Biodiversity Center, Netherlands), Tom D. Breeze (University of Reading, UK), Claire Carvell (UK Centre for Ecology & Hydrology, UK), Catarina Ferreira (IUCN, Belgium), Úna FitzPatrick (National Biodiversity Data Centre, Ireland), Nick J. B. Isaac (UK Centre for Ecology & Hydrology, UK), Mikko Kuussaari (Finnish Environment Institute, Finland), Toshko Ljubomirov (Bulgarian Academy of Sciences, Bulgaria), Joachim Maes (European Commission Joint Research Centre, Italy), Hien Ngo (IPBES, Germany), Adara Pardo (Centre for Ecology, Evolution and Environmental Changes, Portugal), Chiara Polce (European Commission Joint Research Centre, Italy), Marino Quaranta (Council for Agricultural Research and Agricultural Economy Analysis, Italy), Josef Settele (Helmholtz-Centre for Environmental Research - UFZ, Germany), Martin Sorg (Entomological Society Krefeld, Germany), Constanti Stefanescu (Granollers Natural Sciences Museum, Spain), and Ante Vujić (University of Novi Sad, Serbia)

Contents

Abbreviations and glossary

Appendix A1: Member State profiles

ABLE: Assessing Butterflies in Europe project

Additional Modules: These are three modules of the EU-PoMS, in addition to the Core Scheme, which can provide important measures of pollination services, flower visitors, and wider flying insect biodiversity, if Member States choose to implement them. All three require substantial methodological development before they can be adopted as standardised methods as part of EU-PoMS. See Figure 0.1.

Complementary Approaches: These are two modules of the EU-PoMS within the Core Scheme, but which are not yet ready for large-scale adoption. In the case of moths, field validation and refinement of methods is required. In the case of rare and threatened pollinator species, species-specific field methods are required since it is not feasible to monitor them effectively through a large- scale standardised scheme (MVS). See Figure 0.1.

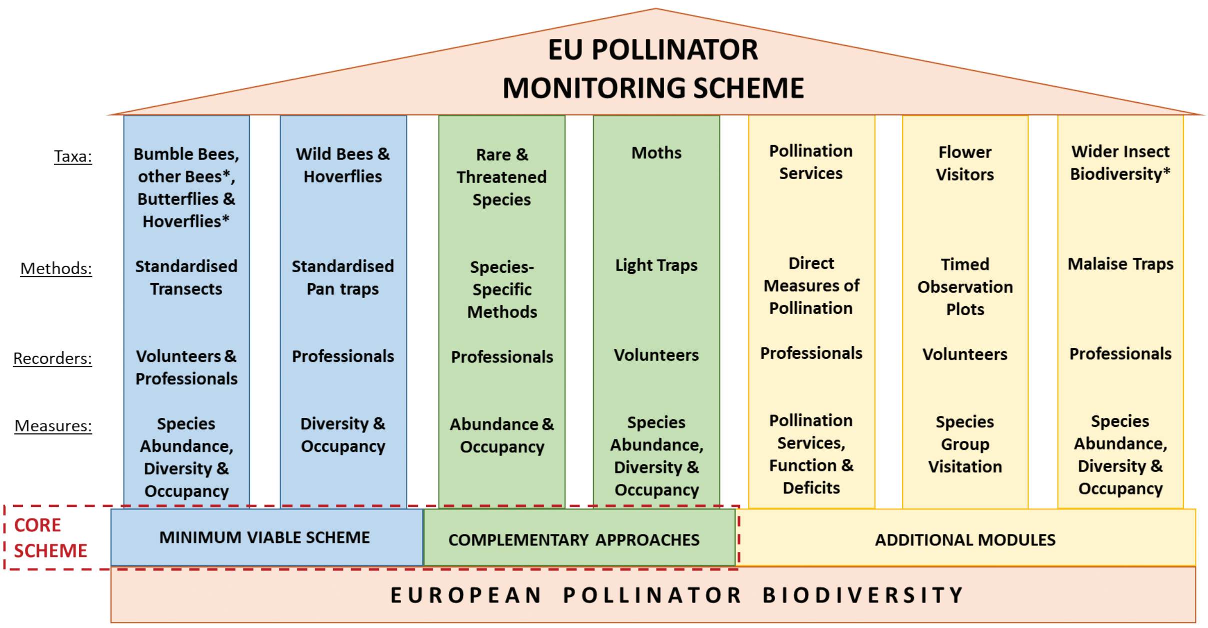
Core Scheme: This comprises four sampling modules of the EU-PoMS which include those taxa which are essential to monitor as part of an EU pollinator monitoring scheme, i.e. wild bees, butterflies, moths and hoverflies, as well as rare and threatened pollinator species. It consists of the Minimum Viable Scheme (two modules) and the Complementary Approaches (two modules). See Figure 0.1.

DG AGRI: The Commission's Directorate-General for Agriculture and Rural Development.

DG ENV: The Directorate-General for Environment.

DG RTD: The Directorate-General for Research and Innovation.

Figure 0.1. Overview of the proposed EU Pollinator Monitoring Scheme (EU-PoMS). The overall scheme comprises a number of components: the Core Scheme are those taxa which are essential to monitor as part of an EU Pollinator Monitoring Scheme (i.e. wild bees, butterflies, moths, hoverflies, as well as rare and threatened pollinator species). Within the Core Scheme is a Minimum Viable Scheme (MVS) which is feasible to implement in the short term and comprises two modules which use standardised transects and pan traps to provide species abundance, diversity and occupancy data on wild bees, butterflies and hoverflies (section 5.2). Complementary Approaches are needed for moths (5.3.1), and for targeting rare and threatened species (5.3.2) which cannot otherwise be monitored through a large-scale standardised scheme. There are three Additional Modules which are optional and could provide important measures of pollination services (5.4.1), flower visitors (5.4.2), and wider flying insect biodiversity (section 5.4.3). For each component of the EU-PoMS the main target taxa, sampling methods, type of recorder, and output measures are given. * indicates that for these groups only a proportion would be identified to species; a number of important details and caveats for all elements presented in this overview are addressed in detail in the main report text.



DPSIR: The Driver-Pressure-State-Impact-Response framework used for the description of environmental problems and their relationships with the socio-economic domain, in a policy- meaningful way.

eBMS: European Butterfly Monitoring Scheme.

EC: European Commission.

EEA: European Environment Agency.

EMBAL: European Monitoring of Biodiversity in Agricultural Landscapes.

EU: European Union. The report was drafted while the UK was in the process of exiting the EU. Therefore EU refers to the bloc's 27 Member States, with a separate reference to the UK as an additional country where appropriate.

EU-PoMS: EU Pollinator Monitoring Scheme, which comprises the Minimum Viable Scheme (two modules), the Complementary Approaches (two modules) and three, optional, Additional Modules. See Figure 0.1.

Europe: Refers to the biogeographic continent.

IACS: Integrated Administration and Control System.

INSPIRE: Infrastructure for Spatial Information in the European Community.

IPBES: The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services.

IUCN: The International Union for Conservation of Nature.

JRC: Joint Research Centre of the European Commission.

LUCAS: Europe's Land Use-Land Cover Area Frame Survey.

MS: Member State of the EU.

MVS: Minimum Viable Scheme of the EU-PoMS, which has two modules which are feasible to implement in the short term and uses standardised transects and pan traps to provide species abundance, diversity and occupancy data on wild bees, butterflies and hoverflies. See Figure 0.1.

Executive Summary

Background and context

Europe supports a rich diversity of wild pollinators, estimated to comprise 2,051 species of bees, 482 species of butterflies, almost 1,000 species of hoverflies plus thousands of species of moths, flies, wasps, beetles and other insects.

Collectively, pollinators provide a wide range of benefits to society including: more than €15 billion per year contribution to the market value of European crops, pollinating around 78% of wild flowering plants which ensure healthy ecosystem functioning, and maintaining wider biodiversity as well as culturally important flower-rich landscapes.

There is increasing evidence that many European pollinating species are declining. For instance, IUCN European Red Lists indicate that 37% of bee species and 31% of butterfly species have declining populations.

However, major gaps remain in our knowledge regarding the status and trends of pollinating insects. There is little data on changes in abundance; butterflies are the best monitored pollinator group but abundance monitoring is only available for around half of the EU Member States. Trends for most pollinators and pollination services are not known in many Member States, especially in southern and eastern Europe, and basic knowledge is lacking even for well-studied groups (e.g. the European wild bee list has 56% data-deficient species).

There are a number of independent initiatives to monitor pollinators across Europe; however, they vary greatly in the taxa, methods, measures, and geographical coverage precluding any general conclusions to be drawn on trends in pollinators at the European level. An exception is the European Butterfly Monitoring Scheme (eBMS), which includes 13 Member States (plus UK[1]) with standardised methods, though monitoring is just starting in many southern and eastern Member States.

A standardised EU pollinator monitoring scheme is therefore essential to overcome outstanding knowledge gaps, to provide high quality data on pollinator and pollination trends, and inform policy and management response options across governance levels.

There are multiple benefits to an EU pollinator monitoring scheme including: societal (e.g. increased food security, agri-food sector employment, protection of pollinator species and habitats), political (e.g. contributing to (inter)-national conservation policy targets, directing policy actions), and scientific (e.g. addressing novel research questions on drivers, biodiversity and ecosystem services).

The European Commission adopted the EU Pollinators Initiative (EPI) in 2018, with a key action to set up a monitoring mechanism for pollinators, with indicators to enable evaluation of actions taken to tackle the decline of pollinators.

Approach to developing an EU pollinator monitoring scheme

This report presents the proposal for an EU Pollinator Monitoring Scheme (EU-PoMS), based on the findings of an expert group of 21 people from 12 European countries. The objectives are to: (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 EU-PoMS comprises a 'Core Scheme', which includes the taxa that are essential to monitor across the EU: wild bees, butterflies, hoverflies, moths, including rare and threatened pollinator species. An overview of the proposed scheme is given in Figure 0.1. The selection of taxa took into account: the proportion of a group which are known pollinators, contributions to crop and wild flower pollination, representativeness of wider biodiversity, vulnerability to environmental change, taxonomic knowledge of the group, and conservation status. Honeybees were excluded from consideration as they are almost entirely managed in Europe, and are already being monitored through other initiatives and projects.

1 The report was drafted during the process of UK exiting the EU. Therefore, EU refers to the 27 Member States comprising the EU, with separate reference to the UK as an additional country.

Within the Core Scheme is the 'Minimum Viable Scheme' (MVS) which includes those taxa which are feasible to monitor in the short term (i.e. bees, butterflies and hoverflies), and comprises two modules which use standardised transects and pan traps to provide species abundance, diversity and occupancy data for these taxa (Figure 0.1). These methods need to be employed by professionals in combination with volunteers wherever possible. A critical assessment of the advantages, biases, practicalities and limitations of a wide range of possible survey methods concluded that this was the best combination of methods to provide high quality, species level abundance data to underpin the Core Scheme.

Alongside the MVS, and within the Core Scheme, are two modules using 'Complementary Approaches' to monitor moths, and to monitor rare and threatened pollinator species (Figure 0.1). The moth module would survey night active moths using light traps, and provide species abundance measures of an additional taxonomic group to the MVS; methods are well developed for this module but require fine tuning and field validation. The rare and threatened species module relies on species-specific field survey methods which is a fundamentally different approach to the MVS; this is necessary as a standardised, large-scale pan-European monitoring scheme is highly unlikely to sample rare species sufficiently to be able to detect changes in their status.

Finally, in addition to the Core Scheme (MVS plus Complementary Approaches) there are three Additional Modules, which are optional: pollination services, flower visitation, and wider flying insect biodiversity (Figure 0.1). These three modules can provide important measures of biodiversity and ecosystem function/services not available through the Core Scheme, but require significant methodological development before they can be implemented at scale in a standardised manner.

A pollination services module would generate data on pollination services to pollinator-dependent crops (and potentially also wild flowers), by providing a more direct measure of the service than the indirect proxy delivered by the Core scheme. Substantial method development and testing is required.

A flower visitation module would provide measures of plant-pollinator interactions for species groups visiting target flowers in timed observation plots. Method development and testing is required.

A wider flying insect biodiversity module would use Malaise traps to survey flying insects, a small proportion of which would be pollinators, and potentially generate species abundance and biomass measures. Substantial method development and testing is required.

Design of the Minimum Viable Scheme (MVS) and additional modules

For the MVS, for the EU, we estimate that a network of 2,000 to 3,000 sites is likely to provide power of >80% to detect changes of ~10% in abundance and species richness over 10 years for major groups (bees, butterflies and hoverflies), and changes of 30% for individual species that occur commonly across Europe[2]. To provide representative coverage, these sites should be allocated in proportion to the land area of Member States, and adjusted to ensure at least 10 sites per Member State (total sites = 2,102; sites per Member State, minimum = 10 and maximum = 238).

For the MVS, for most individual Member States, at least 100 sites per country would be needed to provide sufficient power (>80%) to detect a 30% decline over 10 years for relatively common species or groups of pollinator species at the national level. More sites would be required (e.g. more than 1,000) if lower rates of decline are to be detected (e.g. ≤10% over 10 years), particularly for species or groups occurring in small numbers[2].

A systematic random or stratified-random process to determine the location of sampling sites is recommended to ensure pollinator monitoring is not overly biased towards specific regions, habitats or location of recorders. Where possible, sites should be co-located with the LUCAS (Land Use and Cover Area frame Survey) sample grid, given its unbiased coverage across Europe. Co-location with other site networks (e.g. Long-Term Ecosystem Research or eBMS) is less representative of the overall landscape of Member States.

The estimated cost to establish and run a MVS for the whole of the EU over a 10-year period would be approximately €13.3 million per year. Costs per Member State vary between €50,000 to €1.8 million per year, reflecting differences between the number of sites and national staff and equipment costs.

2 This estimate was based on expert opinion informed by a power analysis using the best available datasets, which are limited in number and geographically biased.

The two Complementary Approaches (within the Core Scheme alongside the MVS) comprise: a moth module with an estimated cost of €1.1 million per year, and a rare and threatened species module estimated to cost €250,000 to €1.0 million per year. The latter would allow targeted monitoring of approximately 50 rare and threatened species per year to inform Red List assessments and potentially measure progress towards international biodiversity targets.

The costs of the three Additional Modules (pollination services, flower visitation, and wider flying insect biodiversity) cannot be estimated until further methodological development and testing have been undertaken.

General and Common Agricultural Policy (CAP) pollinator indicators

The proposed pollinator indicator framework follows the DPSIR (Driver-Pressure-State-Impact-Response) framework of intervention of the European Environment Agency. It suggests a set of indicators that go beyond the State of pollinators and addresses the causes and consequences of pollinator decline. This will help better inform targeted policy responses in the decision-making process.

The proposed State indicators, using data generated by the MVS, are the trends in abundance, species diversity and occupancy. These State indicators make best use of available data from the MVS, are sensitive to change, and produce and resemble existing indicator products of other species groups, such as birds and butterflies.

The proposed Impact indicator is a proxy for pollination services, derived from the MVS data in combination with data on the most important crop pollinator species. More direct measures of pollination services would provide a more robust indicator, but for this, additional data acquisition through an additional pollination module to the Core Scheme would be required.

A range of Driver, Pressure and Response indicators are already available at the Member State and EU level, but information for some key indicators relevant to pollinators (e.g. pesticide exposure) is not currently available.

A CAP indicator should provide an evaluation of the impacts of the CAP, and the measures implemented within, on both pollinators and pollination. In contrast to the general surveillance monitoring of the MVS, this requires concrete hypotheses to be developed on how CAP measures impact pollinators.

CAP monitoring would use the same general State and Impact indicators generated by the MVS to evaluate CAP measures, but require sampling sites in addition to the Core Scheme, to cover the variety and variability of respective CAP measures in each Member State.

The Red List Index could function as an indicator for threatened pollinator species. It is an established indicator for measuring progress towards internationally agreed biodiversity targets, but requires monitoring complementary to the MVS to cover rare and threatened species with restricted ranges.

Taxonomic and data support for the pollinator monitoring scheme

Expert knowledge revealed a rich variety of taxonomic resources available in Europe, although the availability and quality vary markedly between Member States. For the MVS target taxa (bees, butterflies and hoverflies), we provide a detailed stocktake of the availability of national checklists, field guides, handbooks and identification keys, online identification tools, atlases, recording schemes, national Red Lists, internet fora, DNA-barcoding, experts, meetings and organisations.

Taxonomic capacity, in terms of both experts and resources, to support a MVS is highly variable across Europe and taxonomic groups. For bees and hoverflies, taxonomic knowledge and resources are generally better in northwest and central Europe, than in the south and east. For butterflies, taxonomic knowledge and resources are relatively good in nearly all countries; capacity for moths was not assessed.

Guidance is provided for concrete actions on how taxonomic gaps can be reduced to achieve the required levels of species identification needed for the MVS. The approximate costs at the EU level for these actions are, in general order of priority: capacity building and training (€90,000); European pollinator Atlas (€40,000) and national field guides (€700,000), identification keys and checklists (€600,000); DNA barcoding(€1 million for an EU database); online identification tools (€60,000) and mobile Apps (at least €80,000 per species group); digitisation of collections (€400,000); and national Red Lists (€50,000 per taxon).

The estimated capacity building costs per Member State vary depending upon their current level of taxonomic capacity, and range from €117,000 to €422,000. The total initial cost for the EU would be approximately €10.5 million, with ongoing annual costs for the training of recorders and refining taxonomic resources.

A combination of volunteer recorders and professionals will be needed to run a cost-effective EU scheme, and each module within the EU-PoMS requires a different mix of these recorders (Figure 0.1). The roles, levels of expertise and training requirements of these two groups of recorders are assessed, and guidance provided on how to strengthen volunteer recruitment and retention.

Based on existing schemes, options are outlined for processing samples as well as their long-term storage, and for data capture, validation and storage. A central European platform is needed to coordinate the EU-PoMS, develop new taxonomic tools, organise training, store and analyse data and disseminate the results. Coordination at the national level would be needed to implement the MVS, identify samples and store them in the longer-term.

EU-PoMS data should remain open access, so that analyses at both the EU and national level are possible. As the EU-PoMS will use a combination of professional and volunteer recorders, a flexible approach to data ownership will be necessary, where volunteers retain ownership of their data but ownership is shared with the EU-PoMS and any linked existing schemes (e.g. eBMS) have the right to use the data.

A variety of emerging technologies could potentially contribute to the EU-PoMS. These include: automatic image analysis and sound recognition for species identification; repeated counts models; landscape analysis; and, DNA barcoding and metabarcoding. We assess their potential benefits and limitations, current readiness levels and likely timescales for development to a level where they could be incorporated into the EU-PoMS.

Next steps towards an EU pollinator monitoring scheme

Based on the best available evidence and knowledge, a pan-EU pollinator monitoring scheme was designed. However, a number of important knowledge gaps remain which would need to be addressed in order to fine-tune and further improve the design.

A series of pilot studies is recommended to refine methodologies, extend the power analysis of existing survey data, field test additional modules to the Core Scheme, test and validate new indicators, explore pathways to integrate emerging technologies, and increase the taxonomic and recorder capacity to support the EU-PoMS.

Member States are starting from very different positions in terms of: taxonomic capacity; availability of citizen scientists; existing pollinator monitoring infrastructure; knowledge of national pollinators; and bioclimatic conditions. Some Member States are in a position to implement the MVS in the next two years. In contrast, others Member States require substantial capacity building and preparation to achieve this, although they should still be able to implement at least a pilot MVS during the same period.

All Member States have the ability to adopt a pilot scheme within a year, with many going far beyond this; the MVS will require tailoring for national contexts. A second phase of feedback and refinement of the MVS and Core Scheme, through experts working closely with Member State representatives, will be needed to optimise the scheme after the initial phase.

Summary of Recommendations

The following recommendations are based on the expert group proposal for the design of an EU pollinator monitoring scheme and indicators.

Taxa to be monitored in the Core Scheme are wild bees, butterflies, hoverflies, moths, as well as rare and threatened pollinator species. In addition to the Core Scheme, optional modules to be further developed include: pollination services, flower visitation, and wider flying insect biodiversity (Figure 0.1).

For the Minimum Viable Scheme (MVS), for bees, butterflies and hoverflies, a combination of standardised transect walks and pan traps are the most effective methods to provide high quality, species level abundance data. These methods would need to be employed by professionals in combination with volunteers, wherever possible.

Moths and rare and threatened species should be monitored in parallel to the MVS, using Complementary Approaches. Moth surveys using light traps can provide species abundance measures, and while the methods are well developed for this module they require fine tuning and field validation. Rare and threatened species monitoring requires a fundamentally different approach to the MVS with highly targeted species-specific field methods (Figure 0.1).

Across the EU, an estimated network of at least 2,000-3,000 sites in the MVS would provide power of >80% to detect changes of 10% in abundance and species richness over 10 years for bees, butterflies and hoverflies as a whole, and changes of 30% for individual species that occur commonly across the EU. Sites need be located on a systematic random, or stratified-random basis, and wherever feasible be co-located with existing monitoring scheme sites (e.g. LUCAS).

All but the smallest Member State (in terms of area) need at least 100 sites to have sufficient power (>80%) to detect a 30% decline over 10 years for relatively common species, or pollinator groups, in the MVS. Higher numbers of sites would be required (>1,000), if lower rates of decline are to be detected (e.g. ≤10% over 10 years), particularly for species or groups occurring in small numbers.

The estimated cost to establish and run the MVS for the whole of the EU over a 10-year period would be approximately €13.3 million per year. Costs per Member State vary between €50,000 to €1.8 million per year, reflecting differences between the number of sites and national staff and equipment costs.

The estimated additional costs for monitoring moths is €1.1 million per year and for monitoring rare and threatened species is €250,000 to €1.0 million per year. The latter would support targeted monitoring of approximately 50 rare and threatened pollinator species per year to inform Red List assessments.

Three additional modules to the Core Scheme could provide high quality monitoring data on pollination services, flower visitation, and wider insect biodiversity (Figure 0.1). Even though these approaches mostly rely on established methods, a pilot phase will still be required before large-scale deployment across the EU is possible; these costs cannot yet be estimated.

Proposed indicators for the MVS are: a State indicator, for trends in average species abundance; an Impact indicator, as a proxy for crop pollination services based on the most important crop pollinator species; and a range of Driver, Pressure and Response indicators, some of which are already available at the Member State and EU level.

A Common Agricultural Policy (CAP) indicator, with the same general State and Impact indicators, would be used to evaluate CAP measures, and requires sampling sites in addition to the Core Scheme, to cover the variety and variability of respective CAP measures in each Member State.

A Red List Index indicator would be used for measuring progress towards internationally agreed biodiversity targets and requires complementary monitoring to the MVS for rare and threatened pollinator species.

Taxonomic capacity is highly variable across Europe and taxonomic groups, and currently insufficient in many Member States to fully support the MVS. Therefore, substantial investment, in the region of €10 million for the EU, would be needed in recorder training, field guides, identification keys, checklists, DNA barcoding, online identification tools and mobile Apps.

The Core Scheme and Additional Modules will require a series of pilot studies, to refine methodologies, field test modules, test and validate indicators, explore pathways to integrate emerging technologies, and increase the taxonomic and recorder capacity to support the monitoring scheme.

All Member States have the ability to, and thus should, adopt a pilot MVS in the first year, with many going far beyond this. A second phase of feedback and refinement of the Core Scheme will be needed to optimise the scheme after the initial phase.

1 Background and Context

In this Chapter, we present a brief overview of current knowledge regarding the status and trends of European pollinators, including outstanding major gaps (section 1.1). We then provide an overview of the main types of monitoring schemes (section 1.2.1) and those pollinator schemes already established in Europe (sections 1.2.2 – 1.2.4). The wider potential benefits of monitoring pollinators are highlighted in section 1.3, and the international and European policy contexts for a European pollinator monitoring scheme are presented in section 1.4.

1.1 Status and trends of European pollinators

1.1.1 European context

Several reviews highlight global declines in insects (e.g. Sánchez-Bayo & Wyckhuys 2019, Wagner 2020; van Klink et al. 2020), although caution is needed in interpreting some of this complex evidence base (Simmons et al. 2019; Didham et al. 2020). For pollinators, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES[1]) assessment report on pollinators, pollination and food production (IPBES 2016) concluded that there were substantial declines of certain taxa in some regions, particularly in north-west Europe and North America, although evidence was insufficient to draw general conclusions for most of the rest of the world.

Europe is generally recognised to have much of the highest quality and longest-term data for pollinators and other insects, and this has allowed multiple independent assessments of the status and trends of several groups of pollinators. Some evidence comes from the analysis and modelling of huge numbers (sometimes in the millions) of data collected ad hoc by professional and amateur recorders (e.g. Carvalheiro et al. 2013), while other evidence comes from existing systematic monitoring of certain taxa such as butterflies (see section 1.2.2). A brief overview of the current status and trends of major pollinator taxa in Europe is described below (sections 1.1.2–1.1.6). While the understanding of the extent and severity of declines is probably the strongest of any region of the globe, major knowledge gaps still exist across taxa and geographic regions within Europe (section 1.1.7). These pose major barriers to the development and implementation of effective management and policy responses to conserve EU pollinators and sustainably manage pollination services to crops and wild plants. These omissions can only be addressed through a large-scale standardised monitoring scheme (IPBES 2016, Harvey et al. 2020).

Europe supports a rich diversity of wild pollinators, comprising 2,051 species of bees, 482 species of butterflies, and almost 1,000 species of hoverflies plus thousands of species of moths, flies, wasps, beetles and other insects. Collectively, pollinators provide a wide range of benefits to society including: more than €14 billion p.a. contribution to the market value of European crops, pollinating around 78 % of wild flowering plants which ensure healthy ecosystem functioning, and maintaining wider biodiversity as well as culturally important flower rich landscapes (IPBES 2016).

1.1.2 Status and trends of bees (Anthophila)

Since the 1950s wild bees in the Netherlands, Belgium and Great Britain have generally declined in diversity and occurrence (Biesmeijer et al., 2006, Carvalheiro et al. 2013). While bees experienced dramatic losses between the 1950s and 1980s, declines may have slowed since the 1990s (Carvalheiro et al. 2013). There is evidence of parallel declines in bee species richness in many areas along with declines in plant species that are reliant on insect pollinators in (Great Britain) or bee pollinators (the Netherlands) when compared to declines of plants species that are wind- or water-pollinated (Biesmeijer et al., 2006).

In a meta-analysis of long-term observations across Europe over 110 years, Kerr et al. (2015) found consistent trends of bumble bees failing to track warming through time at their northern range limits, range losses from southern range limits, and shifts to higher elevations among southern species. Overall extinction rates of bumble bees, driven by climate change, were found to greatly exceed rates of colonisation, thereby contributing to severe species declines across Europe (Soroye et al. 2020). Modelling shifts in bumble bee distribution showed that, by 2100, up to 36 % are projected to be at high risk from climate change (i.e. losing >80 % of their current range), with 41 % at risk (i.e. losing 50–80 % of their current range), depending on the scenario considered (Rasmont et al., 2015).

Of the 137 UK wild bee species analysed, between 1980 and 2016, 37 % declined in occupancy and 20 % increased while the average trend across the species was a 25 % decline. The declines were greatest between 2006 and 2013, and the average trend across species has since stabilised (Powney et al. 2019). Since 1909, 20 bee and wasp species have become extinct in Britain (Ollerton et al. 2014).

1 https://ipbes.net/

Anthophora quadrimaculata, Nicolas J. Vereecken.

The IUCN European Red List for bees shows that 37 % of bee species have declining populations (excluding data deficient species) and 9 % of all bees, and 26 % of bumble bees, are classified as threatened, while 57 % were data deficient and so could not be assessed (Nieto et al., 2014). Other national Red Lists in Europe indicate up to 40 % of bee species are threatened (IPBES, 2016).

Severe losses of managed colonies of the western honey bee (*Apis mellifera*) have been reported in many western European countries since 1961 (Aizen & Harder, 2009). Between 1985 and 2005, honey bee colony numbers declined by 16 % in Europe, with more severe declines (25 %) in central Europe, but increases (13 %) in the Mediterranean (Potts et al. 2010). A recent global honey bee survey conducted by the Convention on Biological Diversity (CBD 2018) indicated that trends of honey bee populations in Europe were mixed with some countries showing increases (e.g. Germany, Portugal and Sweden), others showing decreases (e.g. Belgium and France), but most with inconclusive or unknown trends (e.g. Italy, Romania and Spain). However, the EU-PoMS includes only wild pollinators since honey bee monitoring is already addressed through several complimentary initiatives and projects (see section 3.2.4).

1.1.3 Status and trends of butterflies and moths (Lepidoptera)

There have been major declines of butterfly populations between the 1950s and 1970s in western Europe, and one third of the species are still declining (van Swaay et al., 2010, van Strien et al. 2019).

The EU Grassland Butterfly Indicator assesses the population trend for 17 typical grassland butterflies. The indicator shows a significant decline of 39 %, mostly occurring in the periods 1990–1998 and 2002–2012, although the rate of decline may have slowed during the last five years compared with the previous period (van Swaay et al. 2019). Modelling shifts in butterfly distributions showed that, by 2080, 70 % are projected to be at high risk from climate change (i.e. losing >80 % of their current range) (Settele et al 2008).

The IUCN Red List for butterflies of continental Europe shows that 31 % of butterfly species have declining populations (excluding data deficient species) and 9 % are classified as threatened (van Swaay et al., 2010). National Red Lists for butterflies indicate that, on average, 27 % of butterfly species are considered threatened within the 24 EU countries with Red Lists at the time of the study (Maes et al. 2019). There is, however, considerable variation between countries, from a low proportion of threatened species in the Mediterranean (only 3 % and 6 % in Spain and Italy respectively) to high percentages in northwest Europe (55 % and 49 % in the Netherlands and Belgium respectively).

Less information is generally available on the trends of moths, although one national study found that total British moth abundance had decreased by 31 % (1969–2006) (Conrad et al. 2006). However, recent evidence suggests that moth biomass may be increasing, implying that a few species are doing well (Macgregor et al. 2019). There is no current European Red List for moths.

Inachis io, Axel Hochkirch

1.1.4 Status and trends of hoverflies (Syrphidae)

Relatively few studies are available on population sizes and trends for hoverflies, compared to bees and butterflies. Keil et al. (2011) assessed temporal changes in species richness of hoverflies from the UK and the Netherlands, comparing museum specimen data prior to and post 1980. Findings were mixed, with species richness increasing in the Netherlands and decreasing in the UK at the fine scale (10 x 10km), while trends differed between countries at the coarsest scale (positive in the UK, no change in the Netherlands). Species distribution modelling indicates that climate change is likely to have variable impacts on three hoverfly genera (*Cheilosia*, *Merodon*, and *Pipiza*), with a mix of range contractions, expansions and shifts (Kaloveloni et al., 2015; Radenković et al., 2017). Northern Europe is projected to become the area of highest species diversity, replacing the current hotspot in central Europe (Milić et al., 2019).

Of the 214 UK hoverfly species analysed between 1980 and 2013, 33 % of species declined in occupancy of 1km squares, and 10 % increased with an average trend across species being a 24 % decline. The average trend gradually declined between 1987 and 2001, but has since stabilised (Powney et al. 2019).

A European Red List of Hoverflies[2] is due for publication in 2021.

1.1.5 Status and trends of other insects

Pollinators include many other insect taxa such as beetles, wasps and thrips, although this is usually a small proportion of the entire group, with the exception of dipterans (Diptera: Syrphidae). Some studies have examined changes in entire insect communities, although it is difficult to establish what proportion of these insects are actual pollinators without sorting and identifying the insect samples. A global meta-analysis found an average decline of terrestrial insect abundance, including some pollinator groups, of ~9 % per decade (Klink et al. 2020). Seibold et al. (2020) report overall declines in arthropods in grasslands and forests in Germany, and another meta-analysis found a 77 % decline in flying insect biomass across 63 protected sites in Germany from 1987 to 2016, likely due to agricultural intensification in the surrounding fields, with protected sites potentially acting as ecological traps (Hallmann et al., 2017). Taken together, these studies suggest that the extent of insect decline in Europe may have been underestimated, although the vast majority of insects in these analyses were probably not pollinators.

2 https://www.iucn.org/regions/europe/our-work/biodiversity-conservation/european-red-list-threatened-species/european-red-list-hoverflies

Cheilosia sp, Tamara Tot

1.1.6 Status and trends of pollination

Our knowledge of which pollinators provide pollination services to crops across Europe has advanced (e.g. Kleijn *et al.* 2015), and while some pollinator species are particularly common crop flower visitors overall, different pollinator communities are important for the pollination of different crops (Garibaldi *et al.* 2013, Garratt *et al.* 2014a). Pollination is strongly linked to both diversity (e.g. Vergara et al., 2009; Garibaldi et al., 2016) and pollinator abundance, but as we do not have regional or national scale pollinator abundance data, estimates of change in pollination services are limited (IPBES 2016).

Sub-optimal pollination has been identified in several European crops, such as UK apple varieties which have about a 20 % pollination deficit (Garratt *et al.* 2014b), but the extent and severity of these shortfalls are unknown for most European crops. While honey bees can be major pollinators of some crops, overall European populations are far below levels required to meet service demands alone, reducing the resilience of many countries to wild pollinator declines (Breeze et al. 2014).

Lautenbach et al. (2012) provide a spatially explicit analysis of global (including Europe), pollination benefits which identify hot spots for the generation of pollination benefits. The authors conclude that while the general dependency of the agricultural economy on pollination seems to be stable from 1993 until 2009, there appears to be an increase in producer prices for pollination-dependent crops over the same period. Nogué et al. (2016) estimate the relative (c.f. actual) provision of pollination service delivery provided by 12 species of bees across Europe, with the aim of identifying potential areas where potential pollination supply coincides with crop demand (hotspots) or not.

1.1.7 Major knowledge gaps

Based on the current state of knowledge and monitoring activities in place (see section 1.2), there remain a number of outstanding gaps which can only be addressed through the development of a large-scale high quality standardised monitoring scheme across Europe:

- In general, most information on the status and trends of European pollinators focuses on diversity and occupancy. However, there is an urgent need to understand how measures of pollinator abundance and biomass are changing, because this is virtually unknown except for some butterfly species.

- While there are good data to estimate changes in population sizes of butterflies, this is almost entirely lacking for wild bees, moths and hoverflies at European and national levels.

- IUCN Red Lists cover European butterflies and bees (hoverflies planned for 2021); however, not all Member States have Red Lists for these groups. Further, the European wild bee list has 57 % data deficient species, indicating the general lack of knowledge of the majority of European bee species.

- Trends in pollination service, and the abundances of key wild insect crop pollinators, are largely lacking beyond local scale studies.

- The geographic extent and temporal changes of pollination deficits in most crops and wild flowering plants is missing.

- Finally, data, studies and taxonomic capacity are much richer in the north and west of Europe, with Mediterranean and eastern European areas much less well studied.

1.2 Overview of current pollinator monitoring activities

1.2.1 Types of monitoring

Monitoring is central to the study of the environment and the management of resources. It provides the primary means to gauge the state of natural resources, understand the causes of change and make predictions based on scenarios of likely interventions. Monitoring programmes have enabled assessment of the effectiveness of policy for improvements of air quality (Reis et al. 2016) and soil health (Tóth et al. 2013), quantified trends in nature and implications for people (Díaz et al. 2019), and tracked the status of water resources to support policy directives (Hering et al. 2010). For example a key element of designing a monitoring programme is an evaluation of costs against the objectives of the monitoring programme and value of the information gained (McDonald-Madden et al. 2010).

1.2.1.1 Surveillance monitoring versus targeted monitoring

Established theory for optimising the design of monitoring (Wintle et al. 2010), recognises the different strengths and weaknesses of targeted versus surveillance monitoring (Table 1.1). Targeted (or question-based) monitoring is designed to be optimal to test *a priori* hypotheses. In contrast, surveillance (or omnibus) monitoring tends to lack clearly stated *a priori* hypotheses, but monitors a range of quantities in order to measure trends or provide *ad hoc* environmental insights (Nichols and Williams 2006). Surveillance monitoring has the potential to detect unexpected patterns of change, the 'unknown unknowns' (Wintle et al. 2010) or 'surprises' *sensu* Hilborn (1987), hence its domination of many areas of science addressing large-scale environmental issues (e.g. diffuse effects such as climate change or pollution). Surveillance monitoring also provides wider benefits beyond informing management and policy decisions, such as educating or engaging the public (Possingham et al. 2012).

1.2.1.2 General criteria for effective monitoring programme

Buckland and Johnston (2017) define five criteria for a well-designed monitoring programme for biodiversity assessment in large regions (e.g. pollinating insects across Europe):

i. Representative sampling locations;

ii. Sufficient sample size;

iii. Sufficient detections of target species;

iv. Representative sample of species (or all species);

v. A temporal sampling scheme designed to aid valid inference.

Representative sampling locations are required to ensure that estimated trends in pollinator populations are representative of the region of interest and not biased towards particular habitats or locations. In an ideal sampling design, representativeness is achieved by simple random or stratified-random site selection (Buckland et al. 2012). Where design-based representativeness is not achievable, model-based representativeness is an alternative approach whereby samples are reweighted, such that their contribution to the overall trend estimate are representative. For example, reweighting can account for uneven sampling of habitats across a region, as applied to some Butterfly Monitoring Schemes (van Swaay et al. 2008), or account for differences between countries in the proportion of an overall population, as used to calculate bird indicators for Europe (Gregory et al. 2005).

Table 1.1. General characteristics of question-based (targeted) and surveillance monitoring designs (adapted from Wintle et al. 2010, Pescott et al. 2015). These two approaches represent the extremes of a continuum which may include intermediate or mixed strategies.

Surveillance Monitoring		Targeted Monitoring
Broad scope (i.e. not based on a single specific question)	**Focus**	Specific purpose (i.e. to discern between competing hypotheses)
Often broad geographic scope or long-running with no pre-defined end-point Potentially many state variables and covariates	**Scope**	Typically, narrow geographic and/or temporal scope Few state variables and covariates
Sampling not optimised to a particular purpose, although trend detection is typical rationale	**Design**	High statistical power to differentiate between hypotheses, or to achieve precise estimates of state variables
Inductive reasoning. The hypothesis is often that change of importance is likely to be detected	**Logical approach**	*A priori* hypotheses articulated

One of the largest cost elements for an EU pollinator monitoring scheme is the number of sampling locations. Sufficient sample size is required to account for the variability in pollinating insects (year-to-year and between different regions of Europe) in order to estimate biodiversity trends with the required precision. Power analysis is typically used to inform sample sizes required to detect change with a given level of precision (Chapter 5).

Pollinators include a number of insect taxa and there are various methods to sample their abundance and diversity. Although all sampling techniques provide an incomplete assessment of the ecological community, the methods adopted for the EU-PoMS should be representative and produce trends that reflect the wider pollinator community (Chapter 4).

The diversity of insects varies markedly across Europe, with a general gradient of highest diversity in the south-east regions compared to the north-west. The abundance of individual species can also fluctuate widely between and within years. An ideal survey is likely to be an annual survey, conducted at the same time each year. Monitoring pollinating insects should also account for the phenology of different pollinator groups and different bioclimatic regions, requiring repeat samples within a year to capture seasonality in numbers of individuals (Chapter 5).

1.2.2 European Butterfly Monitoring Scheme (eBMS)

The European Butterfly Monitoring Scheme (eBMS) is a partnership formed by Butterfly Conservation Europe[3] in April 2016 to bring together data from the Butterfly Monitoring Schemes of different European countries/regions into a consistent format. The partnership currently includes the 22 formal partners (Table 1.2) and 13 affiliated organisations that contribute butterfly monitoring scheme data to support Europe-wide indicators. A formal partnership agreement is in place between all partners to provide a process to request access, under licence, to butterfly monitoring scheme data from multiple schemes in a consistent format. The eBMS partnership and database is coordinated by the UK Centre for Ecology & Hydrology on behalf of Butterfly Conservation Europe.

In 2019 and 2020, the development of the eBMS has been supported by funding from the European Commission through the Assessing Butterflies in Europe (ABLE) project[4].

Data from each eBMS partner is updated on an annual basis and collated into a standardised database. All schemes adopt the same general sampling method of line transects, sampled under standardised conditions by trained professional and volunteer recorders (section 4.3.1). National co-ordinators collect the data and apply quality control procedures. In 2017, almost 56,000 km of transect walks were made across Europe, monitoring each transect an average of 15 times per year to provide counts of adult butterflies throughout the season. The 7,308 transects are spread across the major European biogeographic regions (Figure 1.1). However, relative to the absolute area of the respective regions, the transect density is particularly high in the Atlantic region, moderate in the Continental, Mediterranean and Boreal regions, while the Alpine and

3 https://butterfly-monitoring.net/ebms
4 https://butterfly-monitoring.net/able

Pannonian regions are less-well represented. There is a heterogeneous distribution of transects between Member States, and also between regions in several Member States, in particular in France and Spain. There is a high density of transects for north-west parts of Europe including the UK, Ireland, the Netherlands and Germany but currently limited density or no transects in many other Member States.

The coverage of butterfly monitoring continues to expand across Europe, with more than 3,000 sites monitored each year since 2009 (Figure 1.2). The ABLE project aims to provide tools and materials to support the sustainability of existing schemes and, by working with co-ordinating organisations in Member States, to establish new schemes to enable more representative assessment of the status of butterflies. For example, butterfly counts have recently started in Portugal, Italy, Cyprus and Austria, and the resulting data will be integrated over the coming years to inform the EU butterfly index.

The dataset collated by the eBMS currently comprises more than 4.6 million individual butterfly counts from almost 10,000 transect sites. Although 496 butterfly species have been reported for Europe (Wiemers et al., 2019) and 451 in the EU (van Swaay et al., 2010), many of them are rare and only occur in a few locations. From butterfly transect data collated via the eBMS for the ABLE project, 287 species have been recorded, and for 140 species there is enough data to calculate robust European indexes.

Analysis of butterfly monitoring scheme data collated through eBMS has supported the development of butterfly indicators (van Swaay et al. 2019). The EU Grassland Butterflies indicator (Figure 1.3) was published in the 2019 EU Sustainable Development Goals Monitoring report[5]. The grassland butterfly indicator contributes to Goal 15: Life on Land. Further indicators are in development through the ABLE project.

The eBMS partnership provides a model agreement for wider adoption in support of a European Pollinator Monitoring Scheme (EU-PoMS). It builds upon monitoring within Member States and can add value through standardisation of approaches to monitoring and data collation. A central collation of monitoring data can help support a range of research, conservation and policy use such as the production of indicators (see Chapter 6).

The development of Butterfly Monitoring Schemes for all EU Member States can help support a European Pollinator Monitoring Scheme, building upon the experience of the ABLE project and established schemes that already operate in at least 14 Member States. Butterfly monitoring through citizen science with trained volunteers is an established and sustainable approach. It can be highly cost-effective and although it requires dedicated co-ordination and institutional support it has proven the most successful approach to monitoring any insect group worldwide. As with almost all citizen science approaches, there are biases in the sampling locations. However, statistical models are routinely applied to butterfly monitoring data to account for uneven coverage and enable national and supra-national trends and indicators to be produced (e.g. national indicators, EU Grassland butterflies indicator).

1.2.3 UK Pollinator Monitoring Scheme (PoMS)

The UK Pollinator Monitoring Scheme (PoMS) aims to establish recent and ongoing trends in pollinator populations across the UK. It takes an integrated approach, combining analysis of existing species occurrence (opportunistic) records with new systematic survey data on pollinator abundance collected by a range of volunteer and professional participants. PoMS is focussed on bees and hoverflies (in recognition of evidence that they provide a high proportion of the pollination service to crops and wildflowers), although the surveys sample a wide range of other flower-visiting insects.

The scheme was established in 2017 in response to priority Actions within the National Pollinator Strategies for England, Scotland and Wales to develop and implement a sustainable monitoring framework for pollinators across the UK (e.g. Defra, 2015). PoMS is delivered by the Pollinator Monitoring and Research Partnership: a partnership of NGOs, research institutes and volunteer recording societies, led by the UK Centre for Ecology & Hydrology (UKCEH). The Partnership is funded by Defra, the Welsh and Scottish Governments and by in-kind contributions from Joint Nature Conservation Committee (JNCC[6]) and project partners. The establishment of PoMS followed a two-year design and testing phase (2015–2016) involving identification of knowledge gaps in current monitoring activity, testing of different methods using professional and volunteer recorders with different levels of expertise (Garratt et al., 2019; O'Connor et al., 2019) and consultation with a wide range of stakeholders to propose viable options for survey design and delivery (Carvell et al., 2016).

5 https://ec.europa.eu/eurostat/web/products-statistical-books/-/KS-02-19-165
6 https://jncc.gov.uk/

Table 1.2. European Butterfly Monitoring Scheme (eBMS) formal partners, as of June 2020.

Partner	Country/region	Date joined
Butterfly Conservation Europe	Europe	April 2016
UK Centre for Ecology & Hydrology	UK	April 2016
Helmholtz-Centre for Environmental Research - UFZ	Germany	April 2016
De Vlinderstichting	Netherlands	April 2016
Catalonia BMS	Spain (Catalonia)	April 2016
Finnish Environment Institute	Finland	April 2016
Flanders Butterfly Monitoring Scheme	Belgium (Flanders)	April 2016
Centre des Sciences de la Conservation	France	April 2016
Butterfly Conservation	UK	April 2016
National Biodiversity Data Centre	Ireland	July 2017
Swedish Butterfly Monitoring Scheme	Sweden	July 2017
Luxembourg Institute of Science and Technology	Luxembourg	July 2017
ZERYNTHIA Association	Spain (The Basque Country)	July 2017
Butterfly Monitoring Scheme Spain	Spain (excluding Catalonia and the Basque Country)	July 2017
Društvo za Proučevanje in Ohranjanje Metuljev Slovenije	Slovenia	April 2019
Hungarian Lepidoptera Monitoring Network as part of the Jozsef Szalkay Hungarian Lepidopterists' Society	Hungary	April 2019
Zoolab Department of Life Sciences and Systems Biology University of Turin	Italy	April 2019
TAGIS - Centro de Conservação das Borboletas de Portugal	Portugal	April 2019
Biodiversity Monitoring Switzerland (BDM-CH)	Switzerland	January 2020
Czech Butterfly Conservation Society (BCS)	Czech Republic	March 2020
Butterfly Monitoring Viel-Falter, Department of Ecology, University Innsbruck	Austria (Tirol)	June 2020
Croatia Natural History Museum	Croatia	June 2020

PoMS brings together four key Tasks in an integrated approach across methods and levels of recorder expertise, as shown in Figure 1.4. Under Task 1, species-level records collected opportunistically by amateur experts within the volunteer-led Bees, Wasps and Ants Recording Society[7] and the Hoverfly Recording Scheme[8] are analysed to improve understanding of trends in species distribution (Powney et al., 2019). This includes production of the UK Biodiversity Indicator D1c Pollinating Insects, which in summer 2019 reported on changes in the distribution of 137 wild bee species and 228 hoverfly species (a total of 365 species representing ~70 % of UK species in these groups) from 1980 to 2016 (JNCC, 2019). For the first time, PoMS is also generating country-specific indicators for species recorded in England, Scotland and Wales with sufficient records to model reliable estimates of occupancy (Carvell et al., 2020).

7 www.bwars.com
8 www.hoverfly.org.uk

Argynnis paphia, Axel Hochkirch

Task 2 involves Flower-Insect Timed Counts (FIT Counts): simple systematic surveys collecting data on group-level abundance of flower visitors and plant-pollinator interactions across a variety of countryside and urban habitats. FIT Counts were developed with the aim of encouraging a wide range of people to get involved in pollinator monitoring and have a strong emphasis on citizen science engagement. To take part, recorders spend 10 minutes counting all the insects that land on a particular flower species within a 50cm x 50cm square quadrat, recording these to a broad species group (e.g. honey bees, bumble bees, solitary bees, hoverflies, and other flies etc.). All survey guidance, identification guides, recording forms, how-to videos and summary results can be found on the PoMS webpages[9]. During 2018 and 2019, a total of 1,393 FIT Counts were submitted by members of the public across England, Scotland and Wales including a total of 16,103 insect flower visitors at an average of 9.3 (2018) and 13.2 (2019) insects per count.

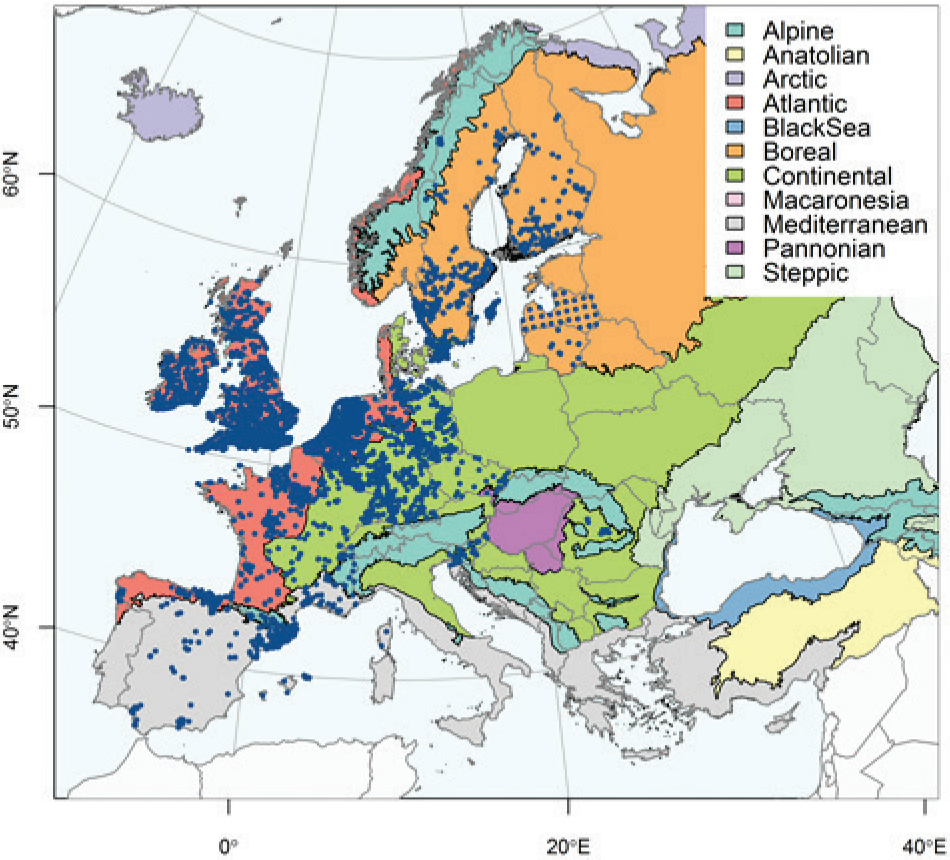
At the core of PoMS is an intensive systematic survey of pollinators and floral resources from a network of 75 randomly selected 1km squares, stratified across agricultural and semi-natural landscapes in proportion to their cover in each country. All PoMS squares in England (36), Scotland (22) and Wales (17) overlap with 1km squares that are part of other environmental monitoring frameworks (NPMS[10], ERAMMP[11]) to benefit from co-location with their invaluable data on wild plant species and changes in habitat condition.

The PoMS 1km square protocol was designed to be implemented by one person (or more) in one day, and involves a set of five pan trap stations (each hosting 3 coloured bowls filled with water) being set out along a diagonal of the square and left for 6 hours, during which time the surveyor collects data on floral resources and habitats and undertakes at least two 10-minute FIT Counts. The protocol is repeated on 4 survey visits to each square between late April and September. During 2019, 236 survey visits were conducted across 74 PoMS squares (mean = 3.1 visits per square). Survey squares were set up, access permission sought and initial surveys undertaken by professionals within the coordinating team in 2017. Subsequently, volunteers were allocated to squares where possible and received 1 to 1 training and equipment needed to carry out surveys independently. By October 2019, 61 trained volunteers had been allocated across 54 PoMS squares, with the remainder surveyed by part-time professional staff.

Pan trap samples are sent to UKCEH (the coordinating institute) using boxes and postage costs provided by the scheme, where they are sorted to broad groups (bees vs hoverflies vs other 'by-catch') and identified to species-level where possible. All sam-

9 https://www.ceh.ac.uk/pollinator-monitoring
10 www.npms.org.uk
11 https://erammp.wales/en

Figure 1.1. Spatial distribution of transects across major biogeographic regions with dark blue dots representing transect sites. Map is based on data with the eBMS as of November 2020 and comprises locations monitored in the field up to 2019.



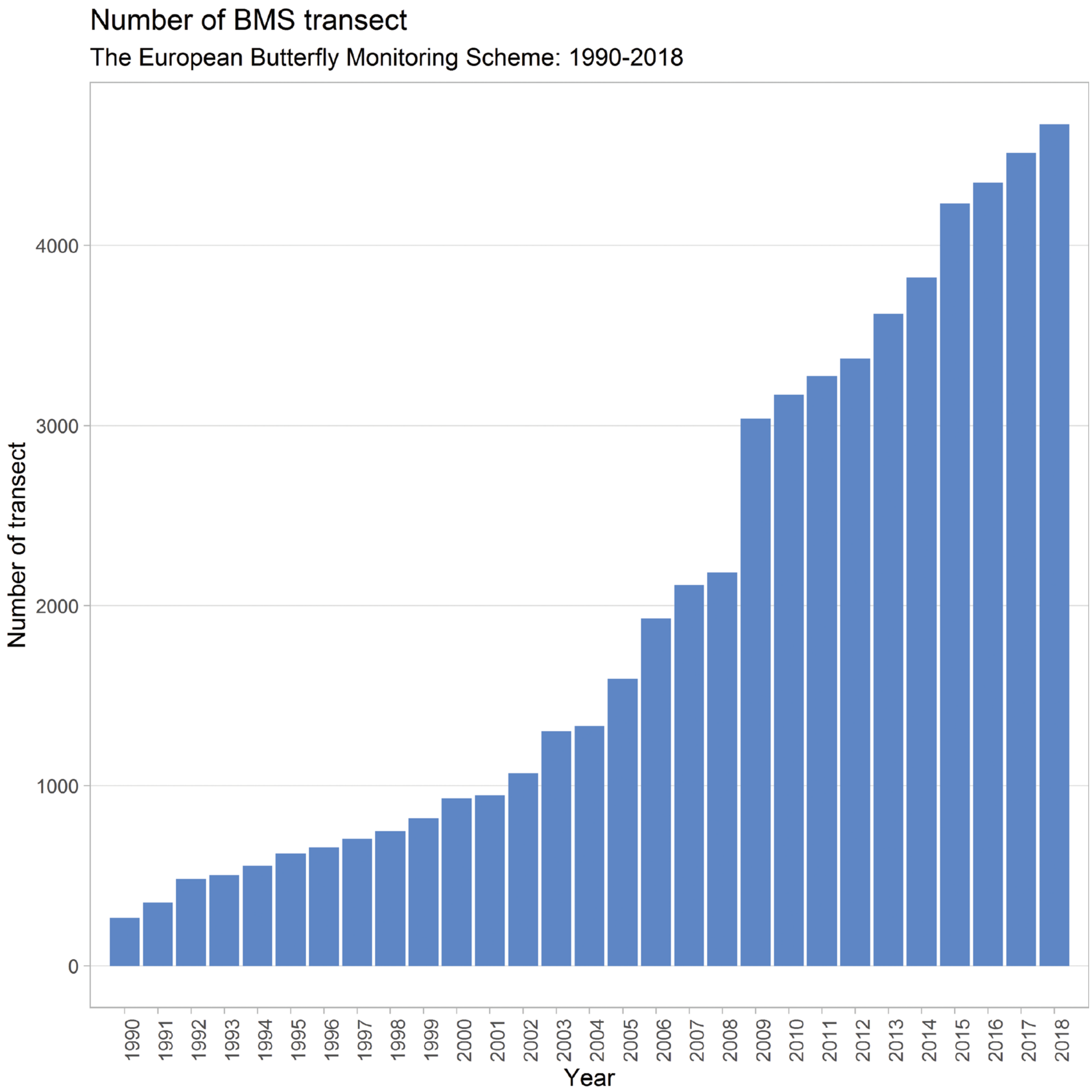
ples are retained and archived in 99 % ethanol and kept under suitable conditions to preserve DNA for potential downstream analyses. All bee and hoverfly specimens not identified by UKCEH staff are then distributed for identification to species-level by consultant taxonomists. During the first two years of the scheme, a total of 88 bee species and 79 hoverfly species were sampled in the pan traps across all sites, these being dominated by common and widespread species but also containing more localised or scarce species representing a range of genera (Carvell et al., 2020).

Under Task 4, integrated models are being developed to combine occurrence records with the systematically collected data (from the 75-site 1km square survey), that typically fill 'gaps' in the occurrence datasets (Isaac et al., 2020). Initial models suggest this approach has the potential to increase the precision of status estimates for a significant proportion of species, thus improving the robustness and scope of future pollinator trends, and consequently relevant biodiversity indicators, for the UK and elsewhere.

Efficient data capture, validation, storage, access and feedback to volunteers are important elements of PoMS. Data from FIT Counts (timed counts to insect group level) and 1 km square surveys (including pan traps) are entered directly by volunteers and the consultant taxonomists (species identifications for bees and hoverflies) into a custom-built Indicia database system[12] through the iRecord website[13]. Photographs of target flowers and insect groups uploaded by volunteers from their FIT-Count observations are checked by staff at UKCEH. Species records from specimens identified from the PoMS 1km survey pan traps are checked against national distribution databases (e.g. to ensure they are not out of potential range) and a sub-set of specimens cross-checked by a second taxonomist, before being shared with the national recording schemes. The full systematic datasets from 'public' FIT Counts and 1km square surveys will be made available under the terms of the Open Government Licence (in fully anonymised form) with the NERC Environmental Information Data Centre (EIDC). This provides a secure long-term data repository, with a DOI for each dataset that ensures attribution and tracking of its use, via citation and acknowledgement of the originators. Finally, feedback is provided to volunteers (citizen scientists), landowners allowing access for PoMS surveys, other stakeholders and funders in the form of annual summary reports at the 1 km square resolution, an annual PoMS Newsletter, online webinar presentations with Q&A and written progress reports.

12 www.indicia.org.uk
13 https://www.brc.ac.uk/irecord/poms-fit-count

Figure 1.2. Histogram of the number of transects monitored each year in Europe since 1990.

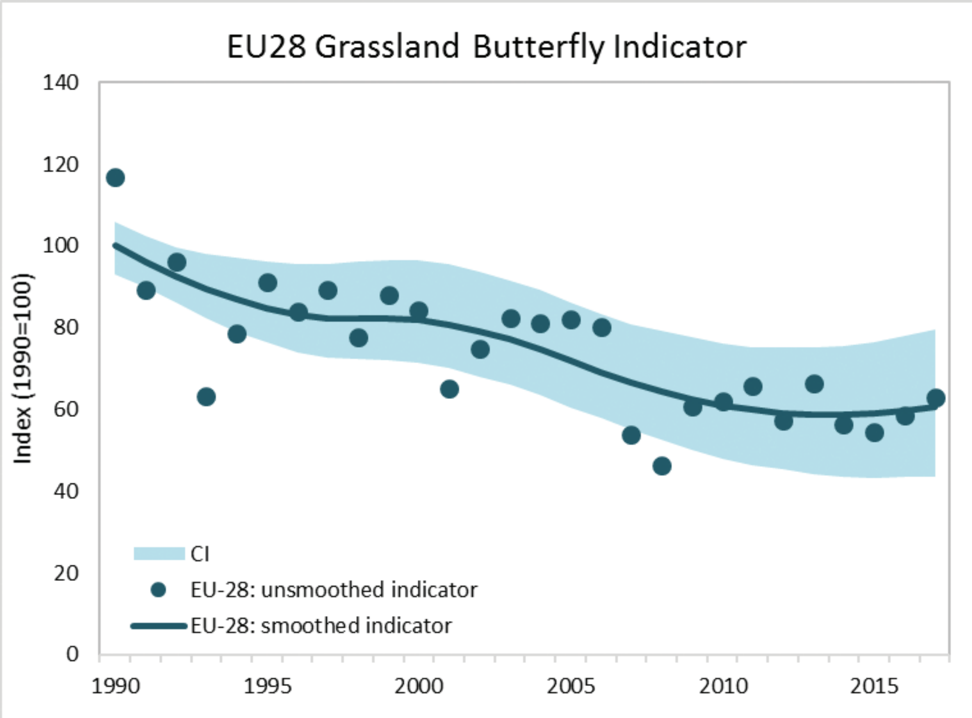


The UK Pollinator Monitoring and Research Partnership aspires to continue running the Pollinator Monitoring Scheme surveys annually to generate long-term standardised data on pollinator abundance and diversity across the UK, with a plan to incorporate Northern Ireland into the scheme during 2020. Links with the academic community will help identify opportunities to maximise the value of data generated under PoMS, to secure external resources to address ongoing knowledge gaps and to enable knowledge transfer and capacity building across other regions.

1.2.4 Other pollinator monitoring schemes

An initial stocktake of pollinator monitoring schemes in Europe up to the end of 2019, identified at least 76 initiatives (see appendices 7.1 to 7.3 for further details), although there are probably more which have recently started or are in development. Twelve European countries have initiatives, and there is at least one European-level scheme, the European Butterfly Monitoring Scheme (eBMS, section 1.2.2); 71 % of all schemes are ongoing and 29 % have recently finished. The majority of schemes have citizen scientists as recorders (70 %), with other schemes having professional recorders (18 %) or a mix of both groups (12 %). The range of pollinator taxa is very broad and many schemes include more than one group: honey bees (42 %), bumble bees (57 %), solitary bees (45 %), butterflies (46 %), moths (28 %), hoverflies (30 %), other flies (21 %) and wasps (21 %). While many schemes focus on one or a small number of groups, others collect all insect taxa, but in most of these cases specimens are stored and not all groups identified. Only 3 initiatives (4 %) include some sort of direct or indirect measure of pollination services. The taxonomic levels at which the schemes operate is highly variable ranging from species and family level identification, through to broad group counts (e.g. bees or flies). The survey methods used are

Figure 1.3. The EU 28 Grassland Butterfly Indicator, one of the European Union indicators contributing as a measure towards the Sustainable Development Goal 15: Life on Land. The grassland butterfly index is a status indicator on pollinators in Europe. It is based on data from 28 EU Member States), measuring the population trends of 17 butterfly species combined by taking the geometric mean of the indices. Values are rescaled such that the smoothed indicator started at 100. The shaded areas represent the 95% confidence limits surrounding the smoothed trend.



also diverse, and include many variations on pan traps, Malaise traps, timed transect walks, timed focal plot observations, hand netting, *ad hoc* collecting, photo identifications, hive monitoring, and suction traps.

It is highly encouraging to document the large number of schemes operating; however, taken together they use a wide variety of approaches; target many different taxa which are identified to various taxonomic levels (often group counts); use a wide array of methods and variants of those methods (some standardised, some not); generate a wide variety of output measures; and cover different geographical areas. This makes it very challenging, if not impossible, to integrate information across schemes, ensure uniform data quality, and produce general indicators of change for different pollinator taxa at national and regional levels. Many of these schemes do provide important and useful outputs at the local or national level, and also have built up strong citizen science communities; however, to generate robust and high quality information on trends of pollinators across the EU requires a large-scale standardised approach as proposed with the EU Pollinator Monitoring Scheme (Chapter 5). The European Butterfly Monitoring Scheme provides probably the best example of a current pan-European approach using standardised methods across multiple countries (section 1.2.2), and the UK Pollinator Monitoring Scheme (PoMS) provides an example of a scheme using standardised methods for multiple pollinator taxa, which is being adopted in other European countries such as Cyprus and Luxembourg (section 1.2.3).

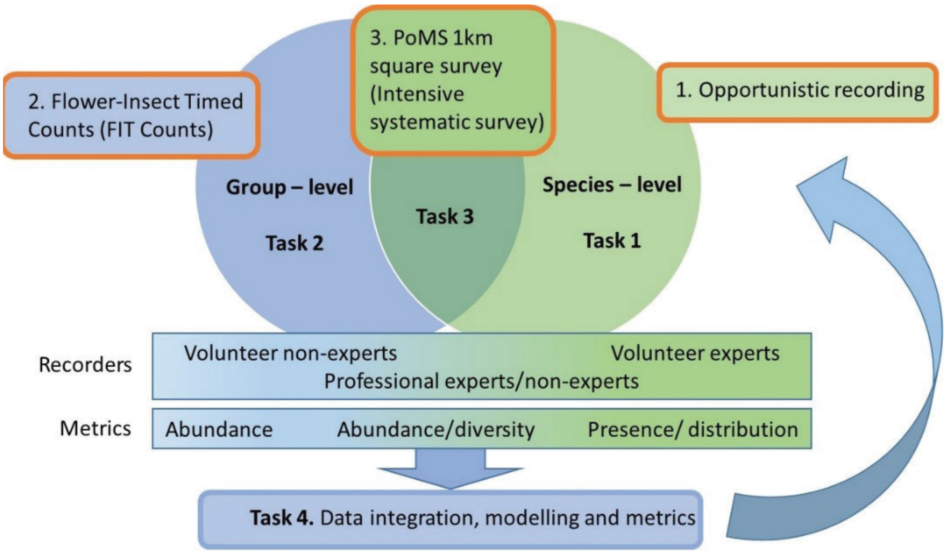
1.3 Potential benefits of monitoring pollinators

The proposed EU-PoMS represents a considerable investment in long-term, high quality data collection. If properly implemented, maintained and acted upon, the scheme will provide a number of societal benefits beyond the immediate benefits to policy and practices. These additional benefits include economic, and social benefits to wider EU society as well as benefits to EU scientific infrastructure. With proper research backing, the data generated by the EU-PoMS will allow European and national scale evaluations of biodiversity, farming, agrochemical and forestry policies in all three of these dimensions.

1.3.1 Economic benefits to wider society

The annual market value of increased production attributed to pollination services was estimated at ~€14.6 billion across the EU in 2009 (Leonhardt et al., 2013), which is more than 100 times the total 10-year costs of the proposed EU-PoMS (Chapter 5). This does not include the additional benefits to initial (e.g. supermarkets) or end consumers (i.e. the public) through reduced

Figure 1.4. The integrated approach to pollinator monitoring taken by the UK Pollinator Monitoring Scheme. See text for a description of Tasks.



prices caused by the greater availability of crops (Gallai et al., 2009; Breeze et al., 2020). Furthermore, demand for insect- pollinated crops across the EU has only continued to grow following the renewable fuels directive (Breeze et al., 2014) and further globalisation of global food systems (Aizen et al., 2019). In addition, recent studies have demonstrated local scale pollination services deficits, where yield has been economically impacted by inadequate pollination (e.g. Garratt et al., 2014); however the scale of such deficits is presently unknown. By facilitating efforts to maintain even a small portion of these economic benefits or reverse deficits, a EU-PoMS would provide significant economic returns relative to its costs and contribute to both food security policy, by securing local supplies of highly nutritious foods (Smith et al., 2015), and reducing food miles.

There is no comprehensive, crop-specific list of EU crop pollinators (Kleijn et al., 2015) and several studies have concluded that the composition of pollinator communities will vary across both space and time. By collecting data over multiple years and countries, the proposed EU-PoMS would, if properly stratified, allow Member States to identify economically important species, monitor their populations in agricultural areas, and facilitate more targeted management. Furthermore, by collecting more detailed information on species ecology over a longer period, a EU-PoMS would provide data to feed into emerging predictive models of pollination services (e.g. Haussler et al., 2017). Using existing spatial data (e.g. CORINE[14]), these models could provide detailed and validated national maps of pollination services across whole countries.

1.3.2 Environmental management benefits

The EU and its members are committed to a number of national and international targets to avoid, reduce and reverse declines of biodiversity in general and pollinators specifically (CBD, 2016). These efforts are hampered by the lack of good quality, long-term data on pollinator abundance and diversity, making it difficult to estimate the scale, extent and driving factors of pollinator decline (Powney et al., 2019). Pollinators are also key to the maintenance of floral communities and the wider biodiversity they support and indicators of overall environmental health. By maintaining even a small portion of pollinator diversity, a EU-PoMS will provide significant benefits to wider biodiversity, ecosystem services and associated policy.

Although the proposed EU-PoMS (Chapter 5) is a surveillance monitoring scheme (see 1.2.1), if site selection is properly stratified to include a range of agricultural landscapes, the data generated can provide a useable measure of both the main drivers of pollinator declines (including pollutants such as pesticides) and the effectiveness of management measures such as agri-environment schemes (Wintle et al., 2010; Raymond et al., 2020). To achieve this stratification, its selection should incorporate other EU data sets such as the Integrated Administration and Control System (IACS[15]) and CORINE. By understanding pressures and responses in this manner, management strategies can be tailored and adapted to address the specific pressures affecting each member state (Lindenmayer et al., 2013; Wood et al., 2015).

14 https://land.copernicus.eu/pan-european/corine-land-cover
15 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/controls-and-transparency/managing-payments_en

Eristalis tenax, Tamara Tot

1.3.3 Benefits to wider society

Citizen science schemes provide an opportunity for the public to engage with nature and conservation in a practical manner that goes beyond traditional education, both through direct participation in the scheme and through engagement with the outputs of the scheme (Gustaffsson et al., 2017). By directly engaging with volunteers, who would form a core component of the site sampling effort, the proposed EU-PoMS presents an opportunity for public participation, education and capacity building, particularly in those countries with limited expertise around pollinators (Chapter 4). Such engagement in the research process is key to enacting deeper changes in public attitudes towards biodiversity, which in turn helps grow support for more transformative changes to the way societies interact with nature (Lindenmayer et al., 2013; Abson et al., 2017). The EU-PoMS could also provide wider societal benefits as well as including education and awareness, raising both through citizen participation in the scheme but also through dissemination of the outputs.

1.3.4 Benefits to wider scientific research

The proposed EU-PoMS represents a significant investment in ecological research infrastructure by developing a stratified site that is both larger and longer term than ecological research efforts funded through current research programmes. If this data were made publicly available then they would allow researchers across Europe to address key research questions that underpin policy and adaptive management in a manner that cannot be achieved by research projects alone, including ones which have not yet been anticipated (Wintle et al., 2010). For example, evaluating the effects of climate change, inter-annual variation in crop pollinator communities (see 1.3.1) and the population level effects of agrochemical use on pollinator communities in various landscapes, all of which require considerable long-term data. Furthermore, addressing these multiple, large-scale research questions via separate research projects would result in considerable duplicated effort, increasing overall costs significantly (see Breeze et al., 2020). By providing a single, well stratified and methodologically unified network, the proposed EU-PoMS would form a cost-efficient research infrastructure for both national and international research.

Beyond these direct benefits to research spending, the proposed EU-PoMS will support scientific capacity building across Europe by linking existing schemes/initiatives (e.g. the numerous existing butterfly monitoring efforts), fostering taxonomic capacity (which is limited or declining in many countries e.g. Breeze et al., 2020) and providing suitable materials for the development and validation of new tools such as national Red Lists and DNA barcoding (Creedy et al., 2019).

1.4 Global, EU and national policy context

The importance of monitoring pollinators has been increasingly recognised by policy makers at national, regional and global level. Internationally, the UN Intergovernmental science-policy Platform on Biodiversity and Ecosystem Services (IPBES)[16] and Convention on Biological Diversity (CBD)[17] highlighted the need to collect long-term high quality data on pollinators and pollination services in order to direct policy and practice responses to address declines (section 1.4.1). This in turn has helped drive several regional initiatives, such as the EU Pollinators Initiative[18] (EPI, section 1.4.2), and many national pollinator strategies[19].

1.4.1 Global policies and initiatives

In 1992 at the Earth Summit, the Convention on Biological Diversity (CBD) was one of the three Rio Conventions established[20], and within the three large objectives of the CBD: (i) conservation of biological diversity, (ii) the sustainable use of its components, and (iii) the fair and equitable sharing of the benefits arising from commercial and other utilisation of genetic resources, the conservation and sustainable use of pollinators arose as a priority - recognising that a global effort was necessary to address the urgent "pollination crisis". At the CBD fifth Conference of Parties (COP V) in 2000, an International Initiative for the Conservation and Sustainable Use of Pollinators (hereafter referred to as the International Pollinator Initiative - IPI) was established[21].

At the following Conference of the Parties (COP VI) in 2002, the International Pollinators Initiative Plan of Action was adopted by CBD Parties[22]. The Plan of Action had four main elements: assessment, adaptive management, capacity building and mainstreaming. Together with the CBD and other relevant organisations, the Food and Agriculture Organization of the United Nations (FAO)[23] facilitated and coordinated the IPI during its first Plan of Action. During this first Plan of Action, several regional and national pollinator initiatives were initiated[24]. The implementation of the IPI and all the work coordinated with the regional pollinator initiatives continued until circa 2014[25] which laid out the essential groundwork and justification for a global assessment on pollinators, pollination and their importance and contribution to food production.

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) was established in 2012 with its first work programme beginning in 2014[26]. IPBES' main objective is to provide decision makers with credible science and knowledge that would inform and support their decision-making processes at local, regional, national and international levels.

The first thematic assessment requested by IPBES member countries was on pollinators, pollination and food production (IPBES 2016). Over the course of two years starting in 2014, top experts from around the world assessed key issues facing decision makers, including the value (and non-monetary value) of pollination and pollinators, status, trends and threats to pollinators and pollination. The assessment also provided several strategic approaches to curb or halt threats to pollinators and outlined opportunities and actions associated with safeguarding pollinators and pollination. By systematically analysing a large body of existing evidence, the report represents a major milestone in the evaluation of current knowledge on pollinators and pollination. It is also the first assessment of its kind that is based on the available knowledge from science and indigenous and local knowledge systems.

In 2016, the IPBES Plenary at its fourth session (February 2016, Kuala Lumpur, Malaysia) approved the assessment's summary for policymakers and approved and accepted the underlying assessment report chapters. Later that year, the key findings from the summary for policymakers (SPM) of the IPBES pollination, pollination and food production assessment report were presented to the CBD's thirteenth Conference of the Parties (COP-13, 2016).

---

16 https://ipbes.net
17 https://www.cbd.int
18 https://ec.europa.eu/environment/nature/conservation/species/pollinators/index_en.htm
19 https://wikis.ec.europa.eu/display/EUPKH/Member+States+initiatives
20 https://www.cbd.int/rio
21 CBD COP decision V/5, section II. International Initiative for the Conservation and Sustainable Use of Pollinators. https://www.cbd.int/decision/cop/?id=7179
22 CBD COP decision VI/5 (annex II). Plan of Action for the International Initiative for the Conservation and Sustainable Use of Pollinators. https://www.cbd.int/doc/decisions/cop-14/cop-14-dec-06-en.pdf
23 http://www.fao.org/home/en/
24 http://www.fao.org/pollination/major-initiatives/international-initiatives/en/
25 CBD COP decision IX/1. In-depth review of the programme of work on agricultural biodiversity.
26 https://ipbes.net/first-work-programme

During COP-13, the Parties welcomed the IPBES summary for policymakers and the full report and endorsed the key messages of the assessment for policy considerations. The CBD encouraged their Parties as well as other entities (i.e. relevant United Nations organisations, other multilateral environmental agreements etc.) to use the assessment's key findings in their efforts to improve conservation and management of pollinators, address drivers of pollinator declines, and shift to sustainable food production systems and agriculture[27].

Within the policy arena, 196 Parties to the CBD, through these decisions, recognised the essential role of the abundance and diversity of pollinators (both managed and wild), for food production, nutrition and human well-being.

Also at COP-13, the Parties requested that the CBD[28] , together with the FAO, review the implementation of the IPI and prepare a draft second Plan of Action, now with the ability to root this Plan of Action in the scientific and knowledge-based evidence from the IPBES assessment in addition to other relevant publications. This second Plan of Action was presented for consideration at the fourteenth Conference of the Parties (COP-14) held in 2018 (November, Sharm El Sheikh, Egypt).

At the COP-14, the Parties adopted the Plan of Action 2018–2030 for the International Initiative for the Conservation and Sustainable Use of Pollinators (IPI-2) for implementation according to national legislation and national circumstances[29]. More specifically, the decision encouraged Governments and other relevant organisations to support and implement relevant activities of IPI-2 through "the integration of appropriate measures into the implementation of national biodiversity strategies and action plans, as well as subnational and local biodiversity strategies and actions plans, as appropriate, and relevant policies, legislation, and programmes." This decision also highlighted the importance of pollinators beyond food production for the maintenance of livelihoods and cultural heritage and practices. Furthermore, the decision reflected global concern for the state and protection of pollinators and pollination services through a reiteration of the important role of pollinators – including wild pollinators, vulnerable biomes and agricultural systems, appropriate land management practices and the role and quality of protected areas for safeguarding pollinators.

Over the last two decades, global efforts towards promoting the conservation and sustainable use of pollinators and pollination functions and services have been gaining momentum. These efforts to date are key to understand how to transition towards attaining more sustainable food systems by fostering the adoption of more sustainable practices among agricultural sectors and other interconnected sectors (i.e. environment, health, energy, water, finance etc.).

1.4.2 EU Pollinators Initiative (EPI)

Public attention has long been drawn to the plight of honey bees in Europe. It was only relatively recently, however, that the much broader phenomenon, the decline of wild pollinating insects, received its due attention and became a major environmental topic. Since 2010, EU-funded projects such as ALARM[30], STEP[31] and European Red List[32] improved our understanding of the problem, and enabled policy makers at EU level to start devising more concrete actions. Following the publication of the groundbreaking report on pollinators by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services in 2016 (IPBES 2016), the stage was set for a discussion on dedicated EU action for wild pollinators.

During the last decade, the EU put in place a range of measures beneficial to pollinators, integrated into environmental and health policies (the Birds and Habitats Directives, the EU legislation on pesticides, and invasive alien species), the Common Agricultural Policy, Cohesion Policy and Research and Innovation policy. However, it was increasingly becoming evident that a more coordinated and integrated approach, bringing all sectors and policies closer together, is needed. The European Parliament[33],[34] and the Council[35] called on the European Commission for more decisive action to protect pollinators and their habitats in order to put an end to their decline.

27 CBD COP decision XIII/15. Implications of the IPBES assessment on pollinators, pollination and food production for the work of the Convention - Recalling decision III/11, annex III, decision V/5, annex I, and decision VI/5, annex II

28 CBD COP decision XIII/15 Implications of the IPBES assessment on pollinators, pollination and food production for the work of the Convention - Recalling decision III/11, annex III, decision V/5, annex I, and decision VI/5, annex II, paragraph 10. Research, Monitoring and Assessment

29 CBD COP decision XIV/6. Conservation and sustainable use of pollinators – Annex I

30 http://www.alarmproject.net

31 http://www.step-project.net

32 https://ec.europa.eu/environment/nature/conservation/species/redlist

33 European Parliament resolution of 2 February 2016 on the mid-term review of the EU's Biodiversity Strategy (2015/2137(INI))

34 European Parliament resolution of 15 November 2017 on an Action Plan for nature, people and the economy (2017/2819(RSP))

35 Council conclusions 13398/16 on Convention on Biological Diversity (CBD), http://data.consilium.europa.eu/doc/document/ST-13398-2016-INIT/en/pdf

In June 2018, the European Commission adopted the EU Pollinators Initiative (EPI)[36], the first-ever EU action to address the decline of wild pollinators. Based on broad stakeholder consultations, the initiative set long-term objectives (towards 2030) and 31 short-term actions to be taken by the EU by 2020 under three priority areas:

- Improving knowledge on pollinator decline, its causes and consequences
- Tackling the causes of pollinator decline
- Raising awareness, engaging wider society and promoting collaboration

The initiative acknowledges that the existing evidence clearly demonstrates an alarming decline of pollinators, which warrants immediate actions. At the same time it also stresses the importance of strengthening the knowledge base. In particular, robust data on the status and trends of pollinators is an indispensable prerequisite for effective conservation actions.

To tackle data gaps, the first action of the initiative aims to set up a monitoring mechanism for pollinators. This report, and the underpinning work carried out by the members of the expert group, is the main deliverable under this action (Chapter 2). It will serve as the basis for the discussions between the Commission and Member States on a common EU monitoring scheme for pollinators. In addition to monitoring pollinator species, the initiative supports the development of other projects and processes, including EMBAL[37], LUCAS grassland module[38] and INSIGNIA[39], that can generate data and information on pressures to pollinators and consequences of their decline. In this way, the initiative follows the DPSIR (drivers, pressures, state, impact and response) model of intervention of the European Environment Agency.

Work under Action 1 of the initiative will not only enable good general understanding of the status of pollinators, it will provide a basis to build robust indicators for monitoring and evaluation of actions taken to tackle the decline of pollinators under EU environmental, agricultural and other sectoral policies. Action 5 specifically aims to integrate a pollinator indicator into the performance monitoring and evaluation framework of the EU common agricultural policy 2021–2027.

Under its third objective, the initiative looks to mobilise society-at-large in pollinator conservation. Citizen science is an important activity in a broader set of actions that the public can take. It can provide decisive support to monitoring schemes that require collection of large amounts of data. The Commission is developing various activities and tools to promote and facilitate citizen science on pollinators, in particular in the context of the future implementation of the EU monitoring scheme.

The EU Pollinators Initiative has been part of the EU Biodiversity Strategy to 2020. It will be reviewed by the end of 2020, and its potential follow-up will be devised in the context of the EU Biodiversity Strategy for 2030[40], which brings an increased ambition to address the decline of pollinating insects. The latter are generally considered as good indicators of the health of terrestrial ecosystems. This makes them an excellent candidate for tracking progress on broader sustainable development policy frameworks, the European Green Deal and UN Sustainable Development Goals (SDGs 2 and 15). It is important to keep this broad added value in mind when discussing the development and deployment of a common EU pollinator monitoring scheme.

References

Abson D, Fischer J, Leventon J, Newig J, Schomerus T, Vilsmaier U, … Lang D (2017) Leverage points for sustainability transformation; Ambio 46, 30–39

Aizen MA, and Harder LD (2009) The Global Stock of Domesticated Honey Bees Is Growing Slower Than Agricultural Demand for Pollination. Current Biology, 19, 915–918.

Aizen M, Aguiar S, Biesmeijer J, Garibaldi L, Inouye D, Jung C, …Seymore C (2019) Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification; Global Change Biology 95, 3516–3527

Biesmeijer JC, Roberts SP, Reemer M, Ohlemueller R, Edwards M, Peeters T, Schaffers A, Potts SG, Kleukers R, Thomas CD, Settele J, Kunin WE (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science 313: 351–354

36 COM(2018) 395 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0395
37 http://ec.europa.eu/environment/nature/knowledge/pdf/embal_report.pdf, http://ec.europa.eu/environment/nature/knowledge/pdf/embal_survey_manual.pdf
38 https://ec.europa.eu/eurostat/statistics-explained/index.php/LUCAS_-_Land_use_and_land_cover_survey
39 https://www.insignia-bee.eu/about/
40 https://ec.europa.eu/environment/nature/biodiversity/strategy

Breeze TD, Vaissière BE, Bommarco R, Petanidou T, Seraphides N, Kozák L, et al. (2014) Agricultural policies exacerbate pollination service supply-demand mismatches across Europe. PLoS ONE, 9, e82996.

Breeze TD, Bailey AP, Balcombe KG, Brereton T, Comont R, Edwards M, Garratt MP, Harvey M, Hawes C, Isaac N, Jitlal M, Jones C, Kunin WE, Lee P, Morris RKA, Musgrove A, O'Connor RS, Peyton J, Potts SG, Roberts SPM, Roy DB, Roy HE, Tang CQ, Vanbergen AJ and Carvell C (2020) Pollinator Monitoring More than Pays for Itself. Journal of Applied Ecology. https://doi.org/10.1111/1365-2664.13755

Buckland S, and Johnston A (2017) Monitoring the biodiversity of regions: Key principles and possible pitfalls. Biological Conservation 214: 23–34.

Buckland S, Baillie S, Dick JM, Elston D, Magurran A, Scott E, Smith R, Somerfield P, Studeny A, and Watt A (2012) How should regional biodiversity be monitored? Environmental and ecological statistics 19:601–626.

Carvalheiro LG, Kunin WE, Keil P, Aguirre-Gutiérrez J, Ellis WN, Fox R, Groom Q, Hennekens S, Landuy WV, Maes D, Van de Meutter F, Michez D, Rasmont P, Ode B, Potts SG, Reemer M, Roberts SPM, Schaminée J, WallisDeVries MF, Biesmeijer JC (2013) Species richness declines and biotic homogenization have slowed down for NW-European pollinators and plants. Ecology Letters 16: 870–878.

Carvell et al. (2020 – publication TBC). Establishing a UK Pollinator Monitoring and Research Partnership (PMRP): Final Report 2017 – 2019.

Carvell C, Isaac NJB, Jitlal M, Peyton J, Powney GD, Roy DB, ... Roy HE (2016) Design and Testing of a National Pollinator and Pollination Monitoring Framework. Final summary report to the Department for Environment, Food and Rural Affairs (Defra), Scottish Government and Welsh Government: Project WC1101

CBD (2016) Decision XIII/15: Implications of the IPBES assessment on pollinators, pollination and food production for the work of the Convention: https://www.cbd.int/doc/decisions/cop-13/cop-13-dec-15-en.pdf

CBD (2018) Global survey of honeybees and other pollinators. CBD/SBSTTA/22/INF/16. https://www.cbd.int/doc/c/e5b4/ac7d/15f-592d0af6224900c95d04b/sbstta-22-inf-16-en.pdf

Conrad KF et al. (2006) Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. Biological Conservation, Vol 132, 279–291.

Creedy TJ, Norman H, Tang CQ, Qing Chin K, Andujar C, Arribas P. [...] Vogler AP (2019) A validated workflow for rapid taxonomic assignment and monitoring of a national fauna of bees (Apiformes) using high throughput DNA barcoding; Molecular Ecology Resources 20, 40–53

Defra (2015) National Pollinator Strategy: Implementation Plan, DEFRA, London: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/794668/pollinators-strategy-imp-plan.pdf

Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan MA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura DA, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Chowdhury RR, Shin YJ, Visseren-Hamakers I, Willis KJ, and Zayas CN (2019) Pervasive human-driven decline of life on Earth points to the need for transformative change. Science 366:eaax3100.

Didham RK. et al. (2020) Interpreting insect declines: seven challenges and a way forward. Insect Conservation and Diversity, Vol 13 doi: 10.1111/icad.12408

Garibaldi LA, Steffan-Dewenter I, Winfree R, Aizen MA, Bommarco R, Cunningham SA, Kremen C. ... Klein AM (2013) Wild pollinators enhance fruit set of crops regardless of honey-bee abundance. Science 339: 1608–1611

Garibaldi LA, et al. (2016) Mutually beneficial pollinator diversity and crop yield outcomes in small and large farms. Science 351: 388–391

Garratt MPD, Coston DJ, Trustlove CL, Lappage MG, Polce C, Dean R, Biesmeijer JC & Potts SG (2014b) The identity of crop pollinators helps target conservation for improved ecosystem services. Biological Conservation 169, 128–135

Garratt MP, Breeze TD, Jenner N, Polce C, Biesmeijer JC & Potts SG (2014a) Avoiding a bad apple: insect pollination enhances fruit quality and economic value. Agriculture Ecosystems and Environment, 184, 34–40.

Garratt MPD, Potts SG, Banks G, Hawes C, Breeze TD, O'Connor RS, Carvell C (2019) Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services. Global Ecology and Conservation, 20.

Gregory RD, A. van Strien, Vorisek P, Meyling AWG, Noble DG, Foppen RPB, and Gibbons DW (2005) Developing indicators for European birds. Philosophical Transactions- Royal Society of London Series B Biological Sciences: 269–288.

Gustaffson KM, Wolf SA and Agrawal AA (2017) Science-Policy-Practice Interfaces: Emergent knowledge and monarch butterfly conservation; Environmental Policy and Governance 27, 521–533

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H., et al. (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLOS ONE, 12, e0185809.

Harvey JA, Heinen R, Armbrecht I, Basset Y, Baxter-Gilbert JH, Bezemer TM, Bohm M, … de Kroon H (2020) International scientists formulate a roadmap for insect conservation and recovery. Nature in Ecology and Evolution 4: 174–176

Haussler J, Sahlin U, Baey C, Smith H. and Clough Y. (2017) Pollinator population size and pollination ecosystem service responses to enhancing floral and nesting resources; Ecology and Evolution 7, 1898–1908

Hering DA, Borja J, Carstensen L, Carvalho M, Elliott CK, Feld A, Heiskanen S, Johnson RK, Moe J, and Pont D (2010) The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. Science of the total Environment 408: 4007–4019.

Hilborn R (1987) Living with Uncertainty in Resource Management. North American Journal of Fisheries Management 7: 1–5.

IPBES (2016) The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. S.G. Potts, V. L. Imperatriz-Fonseca, and H. T. Ngo, (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany

Isaac NJB, Jarzyna MA, Keil P, Dambly LI, Boersch-Supan PH, Browning E … O'Hara RB (2020) Data Integration for Large-Scale Models of Species Distributions. Trends in Ecology & Evolution, 0(0). https://doi.org/10.1016/J.TREE.2019.08.006

JNCC, 2019. https://jncc.gov.uk/our-work/ukbi-d1c-pollinating-insects/

Keil P, Biesmeijer JC, Barendregt A, Reemer M and Kunin WE (2011) Biodiversity change is scale-dependent: an example from Dutch and UK hoverflies (Diptera, Syrphidae). Ecography 34: 392–401

Kerr JT, Pindar A, Galpern P, Packer L, Potts SG, Roberts SPM, Rasmont P, Schweiger O, Colla SR, Richardson LL, Wagner DL, Gall LF, Sikes DS, Pantoja A (2015) Climate change impacts on bumblebees converge across continents. Science 349: 177–180

Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein AM, Kremen C, … Potts SG (2015) Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 6, 7414.

Lautenbach S, Seppelt R, Liebscher J, and Dormann CF (2012) Spatial and temporal trends of global pollination benefits. PLoS ONE e35954

Leonhardt SD, Gallai N, Garibaldi LA, Khulmann M and Klein AM (2013) Economic gain, stability of pollination and bee diversity decrease from southern to northern Europe. Basic and Applied Ecology 14, 461–471

Lindenmayer DA, Piggot MP and Wintle BA (2013) Counting the books while the library burns: why conservation monitoring programs need a plan for action; Frontiers in Ecology and Evolution 11, 549–555

Lyons JE, Runge MC, Laskowski HP and Kendall WL (2008) Monitoring in the Context of Structured Decision-Making and Adaptive Management; Journal of Wildlife Management 72, 1683–1692

Kaloveloni A, Tscheulin T, Vujić A, Radenković S, Petanidou T (2015) Winners and losers of climate change for the genus Merodon (Diptera: Syrphidae) across the Balkan Peninsula. Ecol Model. 313: 201–211

Macgregor, CJ et al. (2019) Moth biomass increases and decreases over 50 years in Britain. Nature Ecology & Evolution, Vol 3, 1645–1649.

Maes D, Verovnik R, Wiemers M, Brosens D, Beshkov S, Bonelli S, Buszko J … Warren MS (2019) Integrating national Red Lists for prioritising conservation actions for European butterflies. Journal of Insect Conservation 23: 301–330.

McDonald-Madden E, Baxter PWJ, Fuller RA, Martin TG, Game ET, Montambault J, and Possingham HP (2010) Monitoring does not always count. Trends in Ecology & Evolution 25:547–550.

Milić D, Radenković S, Radišić D, Andrić A, Nikolić T, Vujić A (2019) Stability and changes in the distribution of Pipiza hoverflies (Diptera, Syrphidae) in Europe under projected future climate conditions. PLoS ONE 14(9): e0221934

Nichols JD, and Williams BK (2006) Monitoring for conservation. Trends in Ecology & Evolution 21:668–673.

Nogué S, Long PR, Eycott AE, de Nascimento L, Fernández-Palacios JM, Petrokofsky G, Vandvik V and Willis KJ (2016) Pollination service delivery for European crops: Challenges and opportunities. Ecological Economics. 128: 1–7.

Nieto A, Roberts SPM, Kemp J, Rasmont P, Kuhlmann M, Biesmeijer JC, … Michez D (2014) European Red List of Bees. Luxembourg: Publication Office of the European Union

O'Connor Rory S; Kunin William E; Garratt Michael PD; Potts Simon G. ….Carvell, C (2019) Monitoring insect pollinators and flower visitation: the effectiveness and feasibility of different survey methods. Methods in Ecology and Evolution, 10 (12). 2129–2140.

Ollerton J, Erenler H, Edwards M. & Crockett R (2014) Extinctions of aculeate pollinators in Britain and the role of large-scale agricultural changes. Science, 346, 1360–1362.

Pescott OL, Walker KJ, Pocock MJ, Jitlal M, Outhwaite CL, Cheffings CM, Harris F, and Roy DB (2015) Ecological monitoring with citizen science: the design and implementation of schemes for recording plants in Britain and Ireland. Biological Journal of the Linnean Society 115:505–521.

Pocock MJO, Newson SE, Henderson IG, Peyton J, Sutherland WE, Noble DG. … Roy DB. (2015) Developing and enhancing biodiversity monitoring programmes: a collaborative assessment of priorities; Journal of Applied Ecology 52, 686–695

Possingham HP, Fuller RA, and Joseph LN. 2012. Choosing among long-term ecological monitoring programs and knowing when to stop. In Design and analysis of long-term ecological monitoring studies (eds. Robert A. Gitzen, Joshua J. Millspaugh, Andrew B. Cooper, Daniel S. Licht.). Cambridge University Press

Potts SG, Imperatriz-Fonseca V, Ngo H, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J and Vanbergen A. (2016) Safeguarding pollinators and their values to human well-being; Nature 540, 220–229

Potts SG, Roberts SPM, Dean R, Marris G, Brown M, Jones R, Settele J. (2010) Declines of managed honeybees and beekeepers in Europe. Journal of Apicultural Research 49: 15–22

Powney GD, Carvell C, Edwards M, Morris RKA, Roy HE, Woodcock BA, and Isaacs NJB (2019) Widespread losses of pollinating insects in Britain; Nature Communications 10: 1018

Radenković S, Schweiger O, Milić D, Harpke A, Vujić A. (2017) Living on the edge: Forecasting the trends in abundance and distribution of the largest hoverfly genus (Diptera: Syrphidae) on the Balkan Peninsula under future climate change. Biol Conserv. 212: 216–229

Rasmont P, Franzen M, Lecocq T, Harpke A, Roberts SPM, Biesmeijer K, Castro L, Cederberg B, Dvorák L, Fitzpatrick Ú, Haubruge E, Mahé G, Manino A, Michez D, Neumayer J, Paukkunen J, Pawlikowski T, Potts SG, Reemer M, Settele J, Straka J, Schweiger O. (2015) Climatic Risk and Distribution Atlas of European Bumblebees. BioRisk 10, special issue, 234 pp.

Raymond CV, McCune JL, Ronser-Katz H, Chades I, Schuster R, Gilbert B and Bennett J (2020) Combining species distribution models and value of information analysis for spatial allocation of conservation resources. Journal of Applied Ecology 57: 819–830

Reis S, Bekunda M, Howard CM, Karanja N, Winiwarter W, Yan X, Bleeker A, and Sutton MA (2016) Synthesis and review: Tackling the nitrogen management challenge: from global to local scales. Environmental Research Letters 11:120205.

Sánchez-Bayo F. & Wyckhuys (2019) Worldwide decline of the entomofauna: A review of its drivers. Biological Conservation, Vol 232, 8–27.

Seibold et al. (2020) Arthropod decline in grasslands and forests is associated with landscape-level drivers. Nature 574: 671–674

Settele J, Kudrna O, Harpke A, Kühn I, van Swaay C, Verovnik R, Warren M, Wiemers M, Hanspach J, Hickler T, Kühn E, I. van Halder, Veling K, Vliegenthart A, Wynhoff I, and Schweiger O (2008) Climatic risk atlas of European butterflies. BioRisk, 1, 1–712.

Simmons et al. 2019 Worldwide insect declines: An important message, but interpret with caution. Ecology and Evolution 9: 3678–3680.

Soroye P, Newbold T, Kerr J (2020) Climate change contributes to widespread declines among bumble bees across continents. Science 367: 685–688

Tóth G, Jones A, and Montanarella L (2013) The LUCAS topsoil database and derived information on the regional variability of cropland topsoil properties in the European Union. Environmental monitoring and assessment 185:7409–7425.

van Klink R, Diana E. Bowler D.E., Gongalsky KB, Swengel AB, Gentile A, Chase JM (2020) Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. Science. 368: 417–420

van Strien AJ, van Swaay CAM, van Strien-van Liempt WTFH, Poot MJM and WallisDeVries MF (2019) Over a century of data reveal more than 80 % decline in butterflies in the Netherlands. Biological Conservation 234, 116–122

Van Swaay CAM, Harpke A, Van Strien A, Fontaine B, Stefanescu C, Roy D, Maes D, Kühn E, Õunap E, Regan EC, Švitra G, Heliölä J, Settele J, Musche M, Warren MS, Plattner M, Kuussaari M, Cornish N, Schweiger O, Feldmann R, Julliard R, Verovnik R, Roth T, Brereton T, Devictor V (2010) The impact of climate change on butterfly communities 1990–2009. Report VS2010.025, Butterfly Conservation Europe & De Vlinderstichting, Wageningen. 22 pp.

van Swaay CA, Nowicki P, Settele J, and Van Strien AJ. 2008. Butterfly monitoring in Europe: methods, applications and perspectives. Biodiversity and Conservation 17: 3455–3469.

Van Swaay CAM, Dennis E, Schmucki R, Sevilleja C, Balalaikins M, Botham M, Bourn N, Brereton T, Cancela JP, Carlisle B, Chambers P, Collins S, Dopagne C, Escobés R, Feldmann R, Fernández-García JM, Fontaine B, Gracianteparaluceta A, Harrower C, Harpke A, Heliölä J, Komac B, Kühn E, Lang A, Maes D, Mestdagh X, Middlebrook I, Monasterio Y, Munguira ML, Murray T, Musche M, Õunap E, Paramo F, Pettersson L, Piqueray J, Settele J, Stefanescu C, Švitra G, Tiitsaar A, Verovnik, R, Warren MS, Wynhoff I & Roy DB (2019) The EU Butterfly Indicator for Grassland species: 1990–2017: Technical Report. Butterfly Conservation Europe.

Wagner DL (2020) Insect Declines in the Anthropocene. Annual Review of Entomology 65: 23.1–23.24

Wiemers M, Balletto E, Dincă V, Fric ZF, Lamas G, Lukhtanov V, Munguira ML, van Swaay CA, Vila R, Vliegenthart A, Wahlberg N. An updated checklist of the European butterflies (Lepidoptera, Papilionoidea). ZooKeys. 2018(811): 9.

Wintle BA, Runge MC, and Bekessy SA (2010) Allocating monitoring effort in the face of unknown unknowns. Ecology Letters 13:1325–1337.

Wood TJ, Holland JM and Goulson D (2015) Pollinator-friendly management does not increase the diversity of farmland bees and wasps; Biological Conservation 187, 120–126

2 Approach to Developing an EU Pollinator Monitoring Scheme

In this Chapter, the composition and objectives of the expert group developing the proposal for an EU pollinator monitoring scheme (section 2.1), and their general approach (section 2.2), are outlined.

2.1 Expert group and approach adopted

In 2019, the European Commission set up a technical expert group to develop a proposal for a European pollinator monitoring scheme as part of Action 1 of the EU Pollinators Initiative (section 1.4.2). The objectives of the group (set out in Appendix 2.1 Terms of Reference) were to:

1. Develop a cost-effective EU pollinator monitoring scheme (EU-PoMS) to monitor pollinators with the following requirements:

    - The scheme should include the most relevant taxa of pollinators (based on different criteria such as vulnerability to environmental pressures, Red List status, functional traits, relative importance for crop pollination, representativeness for biodiversity);
    - The scheme should be able to detect changes in the status of pollinators;
    - The scheme should consider the timing of the EU policy cycle (7 years);
    - The scheme should include EU-wide coverage and should allow harmonised data collection at EU level, based on standardised sampling;
    - The scheme should consider the current level of knowledge on pollinators in the EU Member States;
    - The scheme could be based on professional monitoring, citizen science or a hybrid system;
    - The scheme could have modular components;
    - The scheme should indicate approximate costs according to the level of detection (e.g. short versus long-term perspective).

2. Assess if emerging technologies are fit for the purpose of sampling as an alternative method (e.g. remote sensing of habitats, DNA based sampling).

3. Make a proposal for a general indicator based on the monitoring scheme to assess status and trends of pollinators and specific sub-index tailored to measuring the status of pollinators in agricultural areas.

4. Assess for different options of the scheme:

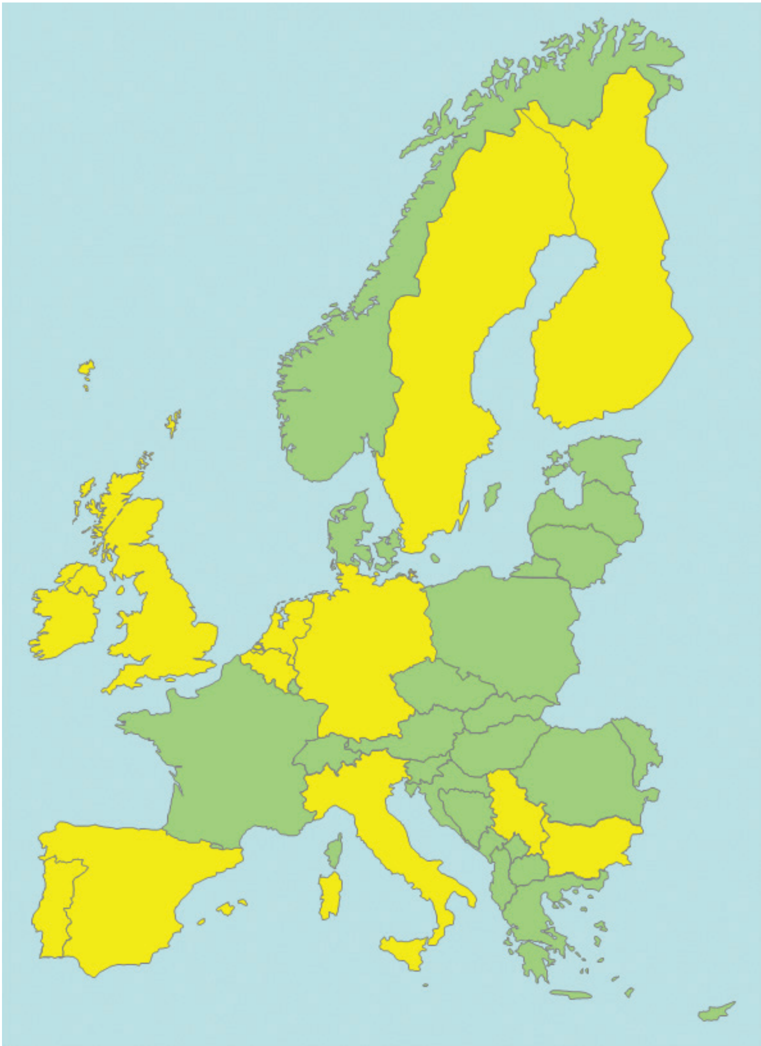
    - The costs for setting up a scheme, training experts, sampling, analysing and producing results, reporting and maintaining the data;
    - The required taxonomical knowledge;
    - The level of detection of change and its relative cost.

5. Present a list of options for the scheme to the Commission.

The expert group comprised 21 individuals from 10 European countries (Figure 2.1, Appendix 2.1) plus representatives from JRC and EEA. The experts were drawn from academia, governmental organisations and NGOs, and their combined expertise covered entomology, pollinator ecology, pollinator conservation, wild flower and crop pollination, agriculture, taxonomy, monitoring scheme design, citizen science, data analysis and management, modelling, indicators, economics, and science-policy interface. Several experts helped develop, or are involved in national and regional pollinator monitoring schemes, with strong links to the wider research, NGO, industry and policy communities.

The technical group started work in April 2019, and met on three occasions (14–15 May 2019, 26-27 November 2019, and 10–11 March 2020). Additional experts attended these meetings, including representatives of JRC, DG AGRI, DG ENV, DG SANTE, DG RTD, DG ESTAT and EEA. The early development of the scheme was presented, and feedback received, at the 27th meeting of

Figure 2.1. Countries (shaded yellow) represented in the expert group for the EU pollinator monitoring scheme.



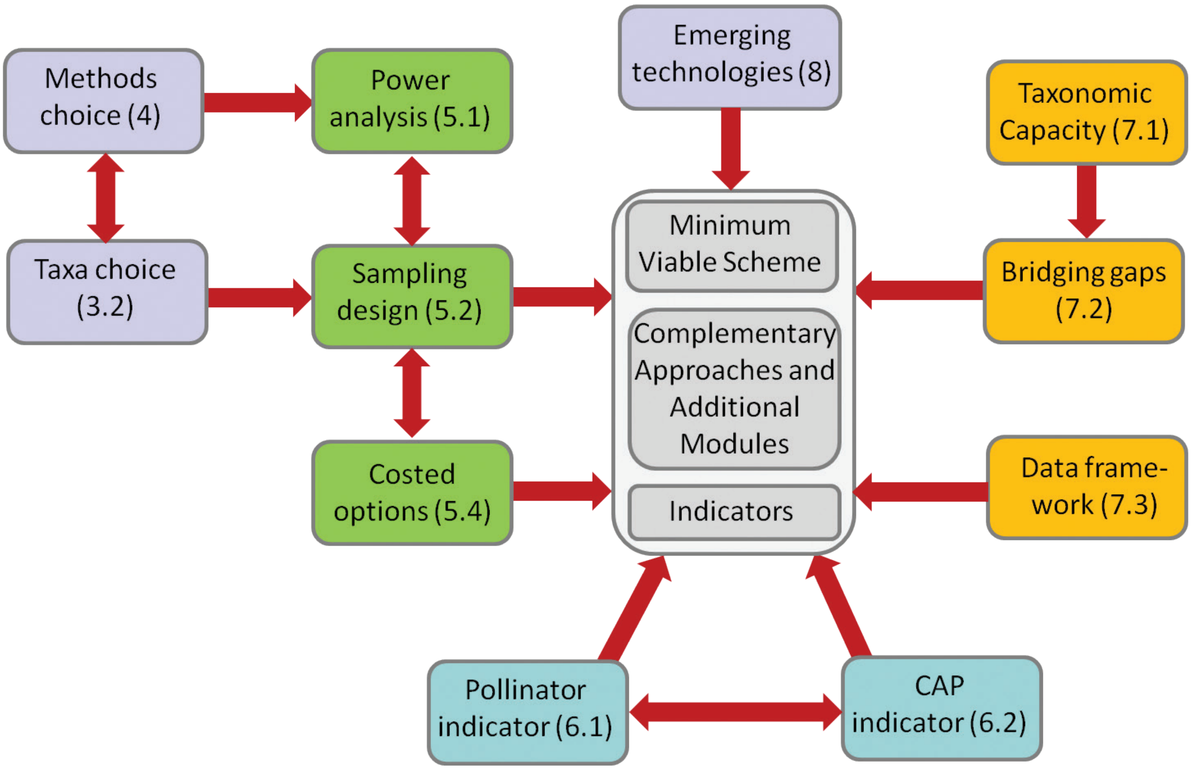
the EC Coordination Group for Biodiversity and Nature (27 September 2019), and at a workshop with Member State experts on pollinator monitoring and indicators (28 November 2019). Project milestones were sent to all DGs and MS for review. The draft report underwent three rounds of review: (i) internal review by the expert group (May 2020); (ii) external review by academic experts (May 2020); and external review by MS experts (June 2020). Full details of the review process are given in Appendix 2.2.

2.2 General framework adopted

In order to deliver a cohesive proposal for a pan-European pollinator monitoring scheme the expert group used a generic framework to develop and integrate the key components of a scheme (Figure 2.2).

Based on the Terms of Reference, the expert group came to a consensus decision on the pollinator taxa to be included in the core monitoring scheme, and those taxa to be included in additional modules (section 3.2). This informed on the appropriate sampling methods, which were critically assessed for their advantages and disadvantages (Chapter 4), and on the datasets the power analysis would use to estimate the replication needed to attain particular levels of change detection (section 5.1). The outcome of the power analysis then underpinned the overall design of the Minimum Viable Scheme (section 5.2) and additional modules for other taxa and measures (section 5.3). The costs of different elements of the scheme were estimated, including the establishment and implementation costs (section 5.4). In parallel to this process, the expert group assessed current Member States' taxonomic capacity to support a scheme (section 7.1) and identified potential pathways to bridge outstanding taxonomic gaps (section 7.2). The various options for data capture, validation, analysis and storage for a Minimum Viable Scheme were evaluated (section 7.3). The indicators for the scheme were developed to provide a set of general indicators (section 6.1) and Common Agricultural Policy (CAP) specific indicators (section 6.2). Finally, the potential for emerging technologies to be included in the scheme in the future was explored (section 8). This general framework was used to underpin the overall structure of the EU pollinator monitoring scheme (Figure 0.1 and Chapter 5).

Figure 2.2. The main elements of the EU pollinator monitoring scheme. Numbers in parentheses indicate reporting section relating to each part. Purple shading includes elements covering sampling methods; green shading includes the analysis of existing data to guide the design and costs of the Core Scheme and Additional Modules; orange shading includes taxonomic and data support elements; blue shading includes the development of indicators; and grey shading is the proposal for Minimum Viable scheme (MVS), complementary approaches and additional modules, and associated indicators. Red arrows show the general flow of data, analytical outputs, and knowledge (not all links are included to maintain clarity).



Appendices

Appendix 2.1 Terms of Reference for the expert group

EUROPEAN COMMISSION

JOINT RESEARCH CENTRE

THIS NOTE IS TO BE SENT VIA ARES TO ve_jrc.bxl.finance

Science and Technology for pollinating insects (STING): A pool of experts to assist the European Commission with Action 1 of the EU Pollinators Initiative

1. Name of the Expert:

2. Context and background information

In June 2018 the Commission adopted a strategy on pollinators. The EU Pollinators Initiative sets strategic objectives and actions to be taken by the EU and its Member States to address the decline of pollinators in the EU and contribute to global conservation efforts. In particular, the initiative calls for measures to improve knowledge regarding pollinator decline (on the status and trends of pollinating species, the causes and consequences of their decline), tackle the causes of this decline (through conservation and management approaches), and raise awareness, engage citizens and promote collaboration (with guidance and incentives, educational material and community projects).

	Name	Family name	Affiliation	Expert registration number	Role
1	Simon	Potts	University of Reading, UK	EX2014D173696	Chair
2	Karin	Ahrné	Swedish University of Agricultural Sciences, Sweden	EX2019D352745	Expert
3	Koos	Biesmeijer	Naturalis Biodiversity Center, Netherlands	EX2019D357927	Expert
4	Tom	Breeze	University of Reading, UK	EX2019D357547	Expert
5	Claire	Carvell	UK Centre for Ecology & Hydrology, UK	EX2019D357583	Expert
6	Catarina	Ferreira	IUCN, Belgium	EX2013D135036	Expert
7	Úna	FitzPatrick	National Biodiversity Data Centre, Ireland	EX2019D356870	Expert
8	Nick	Isaac	UK Centre for Ecology & Hydrology, UK	EX2019D357070	Expert
9	Mikko	Kuussaari	Finnish Environment Institute, Finland	EXT2019D357320	Expert
10	Toshko	Ljubomirov	Bulgarian Academy of Sciences, Bulgaria	EX2019D357033	Expert
11	Marino	Quaranta	Council for Agricultural Research and Agricultural Economy Analysis, Italy	EX2016D292952	Expert
12	Josef	Settele	Helmholtz-Centre for Environmental Research - UFZ, Germany	EX2002B008924	Expert
13	Martin	Sorg	Entomological Society Krefeld, Germany	–	Expert
14	Constanti	Stefanescu	Granollers Natural Sciences Museum, Spain	EX2019D352011	Expert
15	Ante	Vujić	University of Novi Sad, Serbia	EX2019D356755	Expert
16	Jens	Dauber	Thünen Institute, Germany	EX2019D351631	Expert
17	Axel	Hochkirch	Trier University, Germany	EX2019D356688	Expert
18	Bas	Oteman	Dutch Butterfly Conservation, Netherlands	EX2019D352533	Expert
19	David	Roy	UK Centre for Ecology & Hydrology, UK	EX2019D356695	Expert

	Name	Family name	Affiliation	Expert registration number	Role
20	Adara	Pardo	Centre for Ecology, Evolution and Environmental Changes, Portugal	–	Expert
21	Hien	Ngo	IPBES, Germany	–	Expert

Under Action 1A of the initiative the Commission will devise and test an EU-wide pollinator monitoring scheme to ensure the provision of good quality data for assessing the status and trends of pollinator species in the EU and developing a pollinator indicator. A technical expert group will be set up to support this work. The indicator is relevant for Action 5C (The Commission will promote the integration of pollinator considerations in the implementation of the post-2020 common agricultural policy, and will include a pollinator indicator in the performance and monitoring framework once finalised and operational).

This document describes the terms of reference for this technical expert group.

Questions that need to be addressed by a monitoring scheme:

- What are the status and trends of pollinators in the EU?
- What are the status and trends of habitats that support pollinators in the EU?
- How do pollutants impact pollinators? Do pollutants include pesticides with direct impacts (insecticides) or indirect effects (e.g. herbicides and fungicides), as well as other pollutants such as heavy metals or nitrogen which adversely affect plant communities?
- How do crops benefit from pollinators? / How do crops benefit from insect pollination?
- What conservation actions are needed to support pollinators?
- The monitoring scheme is expected to ensure that the information on the status and trends derived from the data collected by the scheme can be linked to the information on the drivers or consequences.

3. Purpose, objectives and scope

1. Develop a cost-effective EU pollinator monitoring scheme (EU-PoMS) to monitor pollinators with the following requirements:

Melanargia galathea, Axel Hochkirch

- The scheme should include the most relevant taxa of pollinators (based on different criteria such as vulnerability to environmental pressures, Red List status, functional traits, relative importance for crop pollination, representativeness for biodiversity)

- The scheme should be able to detect changes in the status of pollinators

- The scheme should consider the timing of the EU policy cycle (7 years)

- The scheme should include EU-wide coverage and should allow harmonised data collection at EU level, based on standardised methods

- The scheme should consider the current level of knowledge on pollinators in the EU member states

- The scheme could be based on professional monitoring, citizen science or a hybrid system

- The scheme could have modular components

- The scheme should indicate approximate costs according to the level of detection (e.g. short versus long-term perspective)

2. Assess if emerging technologies are fit for the purpose of sampling as an alternative method (e.g. remote sensing of habitats, DNA based sampling).

3. Make a proposal for a general indicator based on the monitoring scheme to assess status and trends of pollinators and specific sub-index tailored to measuring the status of pollinators in agricultural areas.

4. Assess for different options of the scheme:

    - The costs for setting up a scheme, training experts, sampling, analysing and producing results, reporting and maintaining the data

    - The required taxonomical knowledge

    - The level of detection of change and its relative cost

5. Present a list of options for the scheme to the Commission.

4. Working approach and methodology

An expert meeting held in Brussels on 14 and 15 May concluded that the expert pool should focus on developing a EU-PoMS for the following taxa: bumble bees and solitary bees (but not honey bees), Hoverflies, butterflies (already covered by eBMS) and moths (as a modular add-on to the main scheme). Taxa not currently proposed for EU-PoMS are wasps, other Diptera and beetles. These may, however, be collected as bycatch in traps.

Specific measures that need to be recorded by a monitoring scheme include: species level where possible, abundance/biomass of some species/groups/target lists, habitats (either local EUNIS, remote sensing), flower visitation rates (indirect measure of pollination), and pollination services (direct measure).

Measures and taxa will be reconsidered and potentially modified in light of developments from the different work streams.

4.1. Work streams

Four work streams run in parallel with an integration work stream to ensure coordination:

1. Sampling design

2. Methods and recorders

3. Taxonomic and data support

4. Indicators

5. Integration

1. Sampling design

Experts: David Roy (lead), Claire Carvell, Tom Breeze, Koos Biesmeijer, Constanti Stefanescu, Nick Isaac, and Martin Sorg (support from Joachim Maes, Chiara Polce)

Key Tasks:

- Assess current schemes and initiatives to identify potential opportunities to build on these and/or secure data sets to help design the EU-PoMS.
- Rapid review of existing national data.
- Develop design for 'Minimal Viable Scheme' (MVS) which all Member States could participate in, or could participate in after a short period of capacity building.
- Develop additional 'modules' to build on the MVS to add further measures and/or taxa
- Propose set of detection levels (e.g. 30% over 10 years with 80% power) and use existing data to conduct power analysis of sampling design to meet this in different Member States; consider EU works on a 7-year policy cycle.
- General design: single overall scheme or nested designs with some high and low intensity sampling sites (e.g. linked to different indicators for EU general pollinator indicator and CAP indicator).
- Propose which landscapes to focus on: all, agricultural, biodiversity hotspots?
- Develop an outline for a common EU protocol for selection of sampling sites.
- Develop costed options for different sampling designs.
- Take into account developments from other work streams.


Megachile pyrenaica, Nicolas J. Vereecken


Eristalis tenax, Adara Pardo

2. Methods and recorders

Experts: Bas Oteman (lead), Úna FitzPatrick, Karin Ahrné, Martin Sorg, and Mikko Kussaari

Key Tasks:

- Critically evaluate the pros and cons of different sampling methods with particular focus on:
    - Quality of data produced
    - Biases and limitations
    - Feasibility of use by citizen scientists as well as professionals
    - Sample processing, identification and longer term storage
    - Costs.

Utilise a combination of existing studies comparing methodologies (e.g. Westphal et al. 2008; Nielson et al. 2011), analysis of datasets from ongoing monitoring or the project, and expert opinion.

This is a priority action as the other work streams need to use this in their decision making for sampling design, taxonomic support and indicators.

- Assess the capability and motivation of different recorders (volunteer/professional vs. expert/non-expert) to undertake the collection and processing of samples.

- Assess the current readiness of emerging technologies which could support EU-PoMS (e.g. metabarcoding, image recognition, AI/machine learning, drones etc.), considering data quality, costs, and biases. Take into account limitations, risks and uncertainties of each, and when they are potentially likely to be 'ready' to be incorporated into existing schemes.

- Take into account developments from other work streams.

3. Taxonomic and data support

Experts: Axel Hochkirch (lead), Marino Quaranta, Ante Vujić, Claire Carvell, Nick Isaac, and David Roy

Key Tasks:

- For Member States make a rapid assessment for key taxa:
    - Current taxonomic expertise
    - Availability of checklists, DNA libraries and reference collections
    - Identification keys for our target taxa – both traditional keys and online tools
    - Training for new (para) taxonomists
    - The 'taxonomic gap' between current and required levels of species identification capability
- Propose pathways for Member States with current capacity below that required for a Minimum Viable Scheme to reach it in the short term (e.g. EU centralised identification) and long term (e.g. train next generation of taxonomists)
- Assess the different options for processing (e.g. locally in Member States or EU centralised), and long storage needs for materials caught in traps, so that they can be used in future for morpho- or DNA-taxonomy
- Assess the options for the data capture, validation, analysis and storage
- Identify key issues around the ownership of data from different sources, bearing in mind the EU Pollinators Initiative stipulates open data policy wherever collection is publicly funded
- Take into account developments from other work streams

4. Indicators

Experts: Jens Dauber (lead), Nick Isaac, Mikko Kussaari, and Adara Pardo

Key Tasks:

Good monitoring starts with a good question. Therefore the indicator group will first focus on identifying the key questions (or indicanda) in the context of pollinator and pollination development in the EU. An existing and helpful framework for this is the DPSIR approach. We will look into Drivers and Pressures affecting pollinators and pollination in the EU and try identifying suitable D- and P-indicators. This may in particular be important for the CAP indicator (identification of beneficial and potentially harmful incentives). For the State (diversity, abundance, genetic diversity etc.) and Impact (pollination and pollination limitation) we will have to differentiate between indicators for a general trend monitoring (unknown unknowns) which is curiosity driven and needed for identification of trends but not suitable for detecting causal relationships and indicators for hypotheses or question driven indicators. The latter could also be more closely related to evaluation of CAP schemes. Several studies have shown that the increasing response from policy and society towards biodiversity loss does not always translate into a reversal of the downward trends of state and the impact of biodiversity. Therefore, we may also have to develop Response-indicators to make the feedback process along the DPSIR cycle transparent. We will have to check which member states have developed pollinator/pollination strategies and which plans for action those may contain.

Among the first steps will be a review of existing indicators in the EU Member States and worldwide. The stocktake of pollinator monitoring activities will be helpful for this task. Any additional information on existing monitoring would be helpful. We may have to consider whether integrated monitoring, i.e. citizen science-based approaches complemented by "professional" monitoring would be a way forward (if sophisticated statistics would be applied). Specific tasks include, to:

- Develop a framework for two types of indicator: (i) general EU pollinator indicators and (ii) a CAP specific pollinator indicator (to assess the impact of policy on pollinators). For this we may have to consider different spatial and temporal scales, e.g. coarse agricultural or land-use statistics at the scale of member states as well as fine grain data from local sampling schemes.

- Assess whether general EU indicator and CAP indicator can use the same sampling design and whether they can be nested or whether separate schemes are needed.

- Consider how best to link policy and impacts on the ground, e.g. IACS data to identify where measures should be enacted and allow maps to be produced where feasible.

- Explore surrogate indicators (e.g. landscape structure, NDVI etc.) which may be useful as indicators

- Identify how both indicators can reflect some sort of measure of abundance;

- Consider how a pollination-related indicator can take account of both supply (i.e. direct measure of available pollinators) and demand (i.e. area and pollinator-dependency of crops).

- Develop a general EU pollinator indicator framework that takes into account:

    - Lessons learnt from the Farmland Bird Index and Butterfly Index;

    - Importance of including crop pollinators/widespread/rare species;

    - Ability to disaggregate per country and per species;

    - Whether a reference level/value is needed;

    - Whether it could/should be spatially explicit.

- Develop framework for CAP indicator taking into account:

    - Performance framework: Output, Results and Impact indicators;

    - Potential to develop at national level

    - Importance of including crop pollinators/widespread species;

    - Ability to disaggregate per country and per species

    - Ability to disaggregate at regional levels within countries in case eco-schemes will be regionalised

    - Whether a reference level/value is needed

    - Whether it could/should be spatially explicit

    - Need to be robust and consider reporting burden

    - Screening of the CAP reform development and of the coming schemes and incentives that may be beneficial or harmful for pollinators and pollination

- Take into account developments from other work streams

5. Integration

Experts: Simon Potts (lead), Josef Settele, David Roy, Axel Hochkirch, Bas Oteman, Jens Dauber. Reviewers: Catarina Ferreira and Toshko Ljubomirov

Key Tasks:

- Facilitate effective and regular communication between work streams

- Participate in key decision points in work streams (e.g. choice of method, indicator) and ensure other work streams are aware of decisions

- Support work stream leaders in managing timelines

- Compile work stream outputs into draft and final reports

- Manage meetings and review processes

- Liaise with Commission, EEA, DG AGRI, DG ENV, DG RTD, JRC, IUCN and other stakeholders

5. Meetings

- A meeting in Brussels in the second half of 2019 (2 to 3 days)

- A meeting in Brussels in the first half of 2020 (2-3 days)

(Meetings: two days for experts but possibly 3 days for work stream leading experts and the chair)

6. Deliverables

The following deliverables will be provided by the pool of experts:

- D1. A report with a proposal outlining different options for a core scheme with a selection of key species per country and an additional package to bring countries to the required level for monitoring pollinators. The possible options are based on experiences in member states and sets requirements for an EU-wide monitoring; specific attention is expected for stratification, spatial and temporal resolution to detect statistically significant trends, aggregation at biogeographical and administrative level (regional, national, EU), links to existing monitoring schemes such as LUCAS; compliance with INSPIRE. The report will assess the cost effectiveness of different monitoring options (estimation of financial resources as well as of statistical robustness)

- D2. A report with a proposal for a statistically robust pollinator indicator, which can detect trends in the composition and relative abundance of the pollinator species community. The report should include a review of existing indicators for pollinators, a set of requirements for the indicator (purpose, conceptual frame, data availability, different taxa of pollinators, specification of key pollinator habitats, red list information, aggregation and components) and a test of the indicator, based on existing data. This work will also devise a version of the indicator specifically tailored to agricultural areas, suitable for inclusion in the monitoring and evaluation framework of the Common Agricultural Policy, and, possibly, other relevant sectoral policies

These deliverables will be provided before 31/12/2020.

7. Expert profiles

Name	Profile overview	Main affiliation
Simon Potts	Simon's research focuses on the links between land use, biodiversity and ecosystem services using a combination of natural, social and economic science approaches. Much of his work looks at ways of reconciling the conflicting demands of food production and biodiversity conservation, with research outcomes aimed at developing evidence-based mitigation options for policy and management applications.	University of Reading (UK)
Karin Ahrné	Karin is chairman of the Swedish expert committee of Lepidoptera, working with species information on the Red List of Swedish Lepidoptera. Her main research interest is biodiversity in human-dominated landscapes.	Swedish University of Agricultural Sciences (SE)
Koos Biesmeijer	Koos is an ecologist working on biodiversity change with a focus on interactions between pollinators and plants. 'He was the first to document large-scale linked declines of pollinator and plants in Europe.	Naturalis Biodiversity Center (NL)

Name	Profile overview	Main affiliation
Tom Breeze	Tom is an ecological economist and his research interests include the social and economic benefits of biodiversity, ecosystem service management, public attitudes towards wildlife, conservation policy, and crop pollination.	University of Reading (UK)
Claire Carvell	Claire is a terrestrial ecologist with a passion for bumble bees and other insect pollinators and broader research interests in the interactions between biodiversity and land-use change. She uses a combination of field observations, experiments, molecular genetics, analyses of long-term datasets and modelling approaches to answer research questions. Her overall aim is to inform agri-environment policy and other management practices that will conserve and enhance diverse pollinator populations, and more widely contribute to understanding sustainable farming systems.	UK Centre for Ecology and Hydrology (UK)
Catarina Ferreira	Catarina leads the European Biodiversity Conservation at IUCN, with responsibility for managing the current project portfolio as well as strategically expanding the programme. Her research has focused on applied conservation science, providing contribution for policy-makers to design species-specific conservation strategies of threatened species.	IUCN (BE)
Úna FitzPatrick	Una manages the National Vascular Plant Database, the National Vegetation Database, and the Irish Pollinator Initiative. Additionally, she has set up various citizen science initiatives on the conservation of Irish plants and pollinators.	National Biodiversity Data Centre (IE)
Nick Isaac	Nick studies how biodiversity is distributed in space, how it is changing over time, and how we measure it. His research combines statistical analysis with the development of tools for making robust inferences from noisy data. Most of his research is based on terrestrial invertebrates in the UK, using data gathered by volunteer citizen scientists.	UK Centre for Ecology and Hydrology (UK)
Mikko Kuussaari	Mikko is a senior scientist active in research on biodiversity in agricultural landscapes, including conservation biology, butterfly ecology and agroecology.	Finnish Environment Institute (FI)
Toshko Ljubomirov	Toshko is an entomologist expert on taxonomy, faunistics, zoogeography, and phylogeny of arthropods, in particular of Hymenoptera.	Bulgarian Academy of Sciences (BG)
Marino Quaranta	Marino's research focuses on the taxonomy, biology and ecology of wild bees, pollination biology of crops and wild plants, and bee-biodiversity changes at different scales.	Council for Agricultural Research and Agricultural Economy Analysis (IT)
Josef Settele	Josef's research focuses on conservation and evolutionary biology of insects; biodiversity and land use; and interdisciplinary cooperation and project co-ordination in biodiversity	Helmholtz-Zentrum für Umweltforschung (DE)
Martin Sorg	Martin's expertise is on nature conservation and natural history, with a focus on insects' ecology, Hymenoptera in particular, systematic entomology, and palaeobiology.	Entomologica (Entomological Society Krefeld), (DE)
Constanti Stefanescu	Constanti's research focuses on the ecology and conservation of butterflies. He coordinates the Catalan Butterfly Monitoring Scheme, which he uses to investigate patterns of diversity and the response of butterfly communities towards global change.	Granollers Natural Sciences Museum, Spain (ES)
Ante Vujić	Ante's research focuses on biodiversity, conservation and taxonomy of Syrphidae in particular.	University of Novi Sad (RS)
Jens Dauber	Jens's research focuses on Diversification of cropping systems, habitats and resources for insects in agricultural landscapes, bioenergy and biodiversity, farmland biodiversity monitoring, ecosystem functions and services in agricultural landscapes. He is the director of the Institute of Biodiversity and leads the working group 'Ecosystem services for sustainable agricultural systems'.	Thünen Institute (DE)

Name	Profile overview	Main affiliation
Axel Hochkirch	Axel's interest spans all kinds of biodiversity research, including its evolution (phylogenetics, phylogeography, evolutionary ecology, biogeography), its dynamics (behavioural biology, ecology, population genetics) and its conservation (conservation biology, conservation genetics).	University of Trier (DE)
Bas Oteman	Bas' main expertise concerns butterflies; computer programming and image recognition; data processing, management and validation; statistical analyses; and geographic information systems and remote sensing.	Dutch Butterfly Conservation (NL)
David Roy	David is the Head of the Biological Records Centre. His research spans biological recording, citizen science, and biological impacts of climate change.	UK Centre for Ecology and Hydrology (UK)
Adara Pardo	Adara is an ecologist interested in plant-animal interactions. She has worked on the determinants of geographical variation in herbivory and her current research focuses on pollination and its drivers within the context of agricultural systems	Centre for Ecology, Evolution and Environmental Changes (PT)
Hien Ngo	Hien is a pollination ecologist with experience in the science-policy interface and policy-related processes. Her work and experience has been on a local to global scale, engaging with many sectors that involve pollinators and pollination services – all with the aim of biodiversity conservation.	UN IPBES (DE)

8. Expert short bibliography relevant for the technical work of the pool

Name	Key publications
Simon Potts	Potts S et al. (2016) Safeguarding pollinators and their values to human well-being. Nature, 540: 220-229
Karin Ahrné	Ahrne K et al. (2009) Bumble bees (*Bombus* spp) along a gradient of increasing urbanisation. PLoS ONE, 4(5):e5574
Koos Biesmeijer	Biesmeijer J et al. (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. Science, 313 (5785): 351-354
Tom Breeze	Breeze T et al. (2017) The costs of beekeeping for pollination services in the UK – an explorative study. Journal of Apicultural Research, 56: 1-8
Claire Carvell	Carvell C et al. (2017) Bumblebee family lineage survival is enhanced in high-quality landscapes. Nature, 543: 547-549
Catarina Ferreira	Ferreira C et al. (2016) Naturalists: Hail local fieldwork, not just global models. Nature, 534: 326.
Úna FitzPatrick	Fitzpatrick U et al. (2007) Building on IUCN Regional Red Lists to Produce Lists of Species of Conservation Priority: a Model with Irish Bees. Conservation biology: the journal of the Society for Conservation Biology, 21: 1324-1332
Nick Isaac	Isaac N et al. (2015) Bias and information in biological records. Biological Journal of the Linnean Society, 115(3): 522–531
Mikko Kuussaari	Kuussaari M et al. (2016) Weather explains high annual variation in butterfly dispersal. Proceedings of the Royal Society B (Biological Sciences), 283:20160413
Toshko Ljubomirov	Ljubomirov T. (2011) Range re-evaluation and morphological recognition in two West Palaerctic species of Myrmilla Wesmael, 1851 (Insecta: Hymenoptera: Mutillidae). Annalen des Naturhistorischen Museums in Wien. B, 112: 19-72.
Marino Quaranta	Quaranta M et al. (2004) Wild bees in agroecosystems and semi-natural landscapes. 1997-2000 collection period in Italy. Bulletin of Insectology, 57 (1): 11-61
Josef Settele	Settele J et al. (2018) Conservation biological control: Improving the science base. Proceedings of the National Academy of Sciences of the United States of America, 115 (33): 8241 - 8243
Martin Sorg	Sorg M et al. (1988) A new species of bethylid wasp (Hymenoptera) from New Zealand, with comments on its life history and host. Journal of Natural History, 22(6):1483-1488

Name	Key publications
Constanti Stefanescu	Stefanescu C et al. (2017) Back to Africa: autumn migration of the painted lady butterfly Vanessa cardui is timed to coincide with an increase in resource availability: Autumn migration of Vanessa cardui. Ecological Entomology, 42: 737-747
Ante Vujić	Vujic A et al. (2019) Hidden European diversity: A new monotypic hoverfly genus (Diptera: Syrphidae: Eristalinae: Rhingiini). Zoological Journal of the Linnean Society, 185(4):1188-1211
Jens Dauber	Dauber J et al. (2016) To integrate or to segregate food crop and energy crop cultivation at the landscape scale? Perspectives on biodiversity conservation in agriculture in Europe. Energy Sustainability and Society (1) 6:25
Axel Hochkirch	Hochkirch A. Biodiversity: Factor in species' conservation value. Nature, 547(7664):403-403
Bas Oteman	Oteman B (2019). NDFF Butterfly Data. Version 1.3. Butterfly Conservation Europe. Occurrence dataset https://doi.org/10.15468/ah1ln9 accessed via GBIF.org on 2019-06-04
David Roy	Roy D et al. (2015) Similarities in butterfly emergence dates among populations suggest local adaptation to climate. Global Change Biology, 21: 3313-3322
Adara Pardo	Pardo A and Borges PAV. (2020). Worldwide importance of insect pollination in apple orchards: a review. Agriculture, Ecosystems and Environment, 293. doi:10.1016/j.agee.2020.106839
Hien Ngo	IPBES (2016): Summary for policymakers of the assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. Potts SG, Imperatriz-Fonseca VL, Ngo HT, Biesmeijer JC, Breeze TD, Dicks LV, Garibaldi LA, Hill R, Settele J, Vanbergen AJ, Aizen MA, Cunningham SA, Eardley C, Freitas BM, Gallai N, Kevan PG, Kovács-Hostyánszki A, Kwapong PK, J. Li, X. Li, D. J. Martins, Nates-Parra G, Pettis JS, Rader R, and Viana BF (eds.). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 36 pages.

9. Technical contact person

Joachim Maes: joachim.maes@ec.europa.eu

Appendix 2.2 Overview of the review process

Internal review by expert group (May 2020)

List of reviewers: Adara Pardo, Ante Vujic, Axel Hochkirch, Bas Oteman, Catarina Ferreira, Claire Carvell, Constanti Stefanescu, David Roy, Hien Ngo, Jens Dauber, Josef Settele, Karin Ahrne, Koos Biesmeijer, Marino Quaranta, Martin Sorg, Mikko Kuussaari, Nick Isaac, Simon Potts, Tom Breeze, Toshko Ljubomirov, and Una Fitzpatrick.

Number of comments addressed: 788.

External review by academic experts (June 2020)

List of reviewers: David Kleijn (Chair Plant Ecology and Nature Conservation, Wageningen University, NL); William Kunin (Professor of Ecology, University of Leeds, UK); Lynn Dicks (Lecturer in Animal Ecology, University of Cambridge, UK).

Number of comments addressed 377.

External review by Member State and Commission experts (June 2020)

List of reviewers providing feedback: 15 representatives of Member States and 8 representatives from Commission DGs, Joint Research Centre and Agencies.

Number of comments addressed: 176

3 Selection of Taxonomic Groups for the EU Pollinator Monitoring Scheme

In this Chapter we provide an overview of diversity of pollinator groups across Europe (section 3.1), and then present the rationale for selecting those taxa (section 3.2.1): to include in the core EU pollinator monitoring scheme (section 3.2.2), to include as additional modules to the Core Scheme (section 3.2.3), and those not included in the scheme (section 3.2.4), as well as the types of measures the Core Scheme will focus on (section 3.2.5).

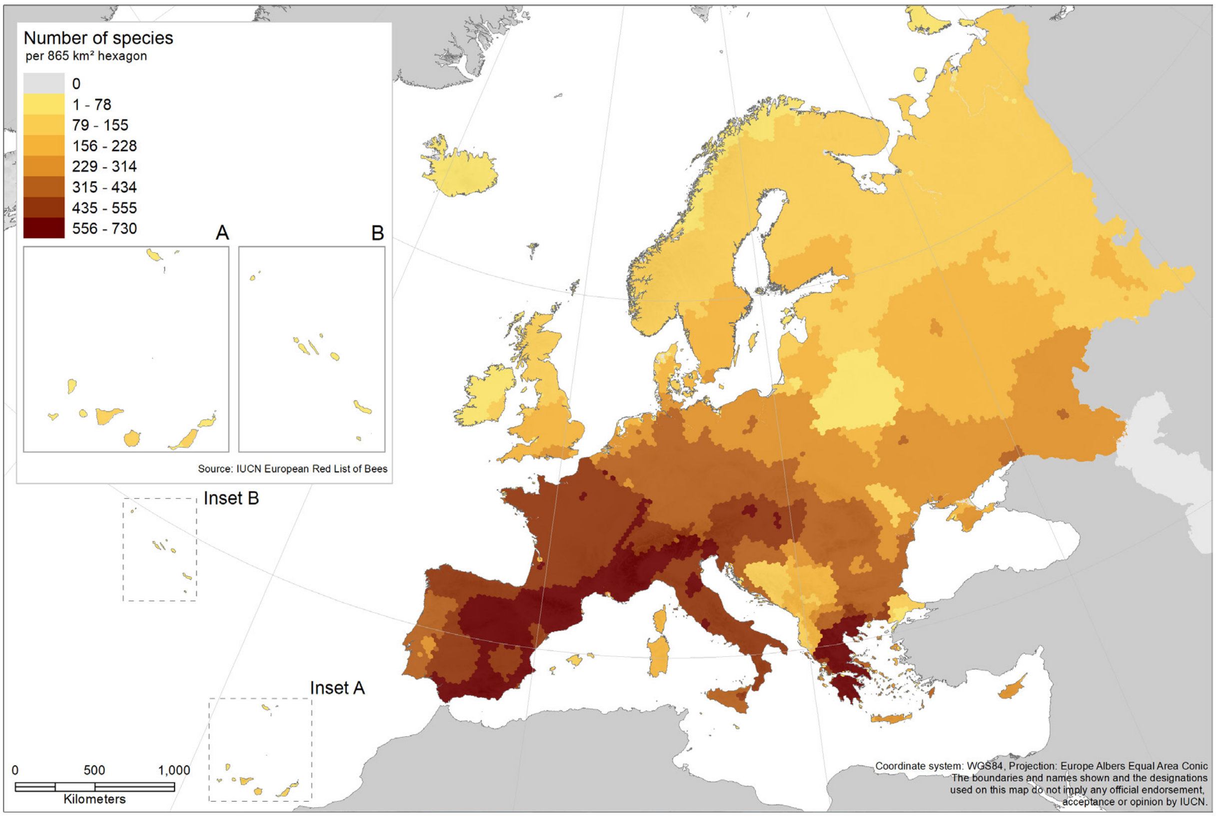
3.1 Overview of European pollinators

Europe hosts a rich diversity of insect pollinators displaying a variety of life histories and pollinating a wide range of wild plants and cultivated crops. The main groups of insect pollinators include bees, hoverflies, butterflies, moths, beetles and wasps, although members of other taxa may also be pollinators, such as thrips (see Chapter 1 for details).

3.1.1 Bees (Anthophila)

Bees constitute a highly diverse group among pollinators. For geographical Europe (excluding the republics of the Caucasus), the most updated accounts report around 2,051 species (Nieto et al., 2014; Rasmont et al., 2017; Ascher and Pickering 2020). Bees occur in all terrestrial habitats in Europe with the highest species richness in southern Europe, and particularly the Mediterranean climate region (Figure 3.1).

Figure 3.1. Species richness of European bees (from Nieto et al. 2014).



European bee species can be divided into six families and two main groups: long-tongued bees of the families Apidae and Megachilidae, and short-tongued bees of the families Andrenidae, Colletidae, Halictidae and Melittidae. While globally there are around 20,000 bee species, Europe has about 10% of this bee diversity, even though the land area is only 7% of the global total. The most diverse family of bees is the Apidae (561 species), which includes the honey bee (almost entirely managed throughout Europe) and the bumble bees (*Bombus* spp.). Cuckoo, or kleptoparasitic, bees make up approximately 18% of European bees, and these taxa generally do not collect pollen or nectar, making them relatively poor pollination service providers; nonetheless, they are of conservation interest, and may be good indicators of healthy populations of their host species. About 20% (~400 species) of the bee fauna is endemic. Southern Europe has a high number of endemic bee species, with much lower endemism in temperate parts of Europe due to many species having large ranges extending far into Asia (Figure 3.2).

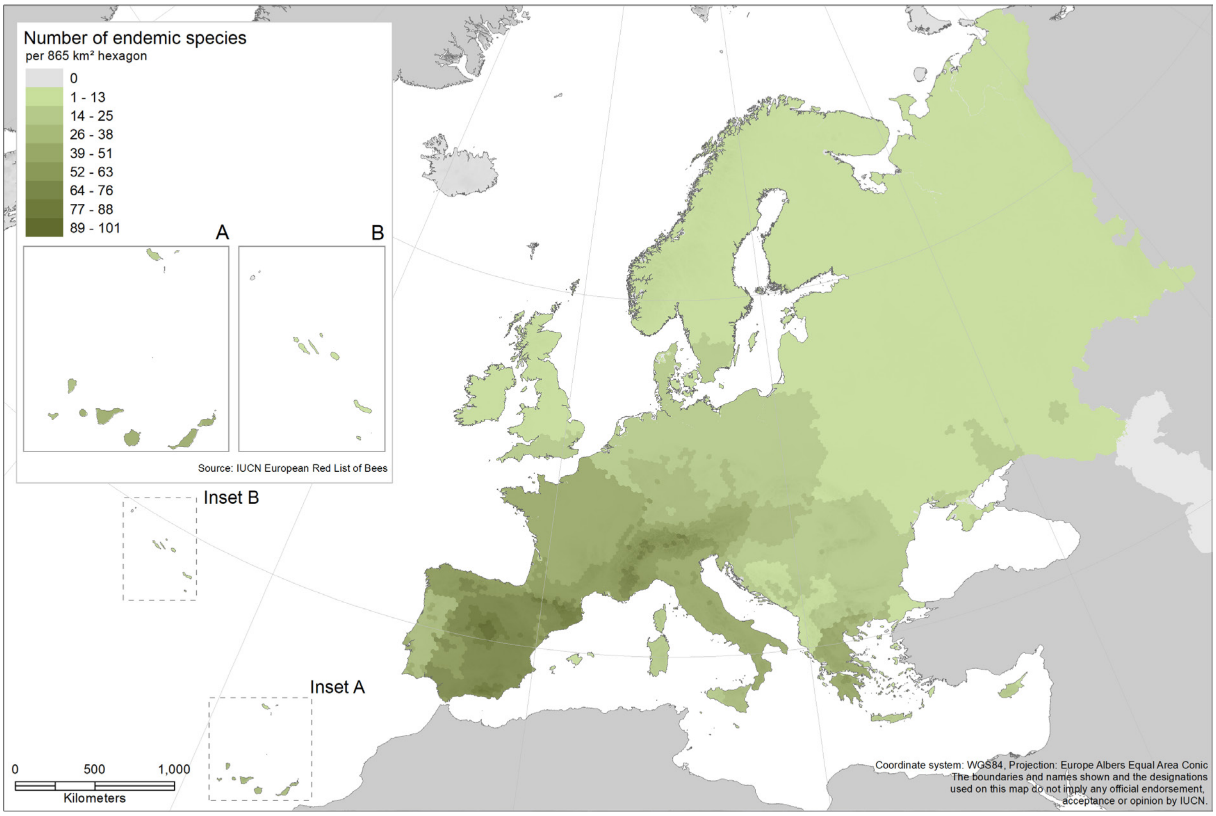
Nomada goodeniana, Andrew Byrne

Osmia caerulescens, Riccardo Mattea

3.1.2 Hoverflies (Syrphidae)

Hoverflies are commonly known as flower visitors and pollinators, as well as mimics of bees and wasps. The larvae of some species are aphid-feeders and so can act as biocontrol agents in various crops. Syrphid larvae can be found in almost every habitat, except caves and the deep water of rivers and lakes, and exhibit an unusual diversity of larval biology for a single family of Diptera. For nearly all adult syrphids their main food is nectar and pollen, thus syrphids often constitute a conspicuous component of the flower-visiting insect fauna. Some syrphid species (e.g. 16% in Greece) visit flowers which produce only pollen, such as the flowers of conifers, the various oak species, grasses, plantains and sedges (Vujić et al., 2020).

Figure 3.2. Distribution of endemic bees in Europe (from Nieto et al. 2014).

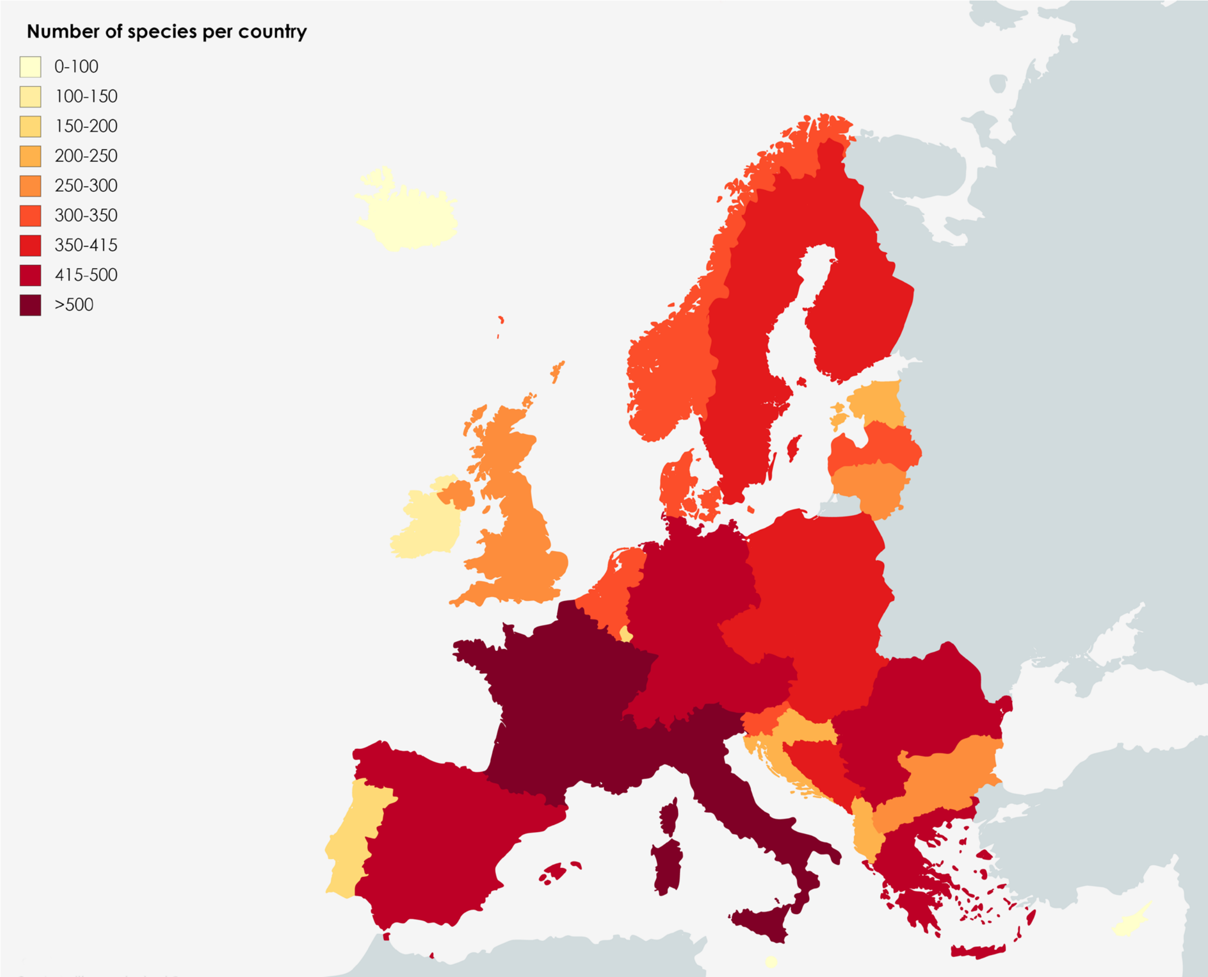


Episyrphus balteatus, Tamara Tot

A total of 979 syrphid species are known in Europe (Speight et al. 2020), with the highest species richness in southern and central Europe, and particularly the Mediterranean climate region (Figure 3.3). In general, because syrphid larvae occur in such a wide range of microhabitats, the greater the structural complexity of a habitat, the greater is its associated diversity. Natural or semi-natural forest, where structural complexity is very high, support the greatest diversity of syrphid species (Vujić et al., 2020).

About 16% (164 of 983 species) of the hoverfly fauna is endemic to Europe (Speight et al., 2020). The Mediterranean, and especially east Mediterranean islands, and high mountain ranges support a higher proportion of endemics than other biogeographical zones.

Figure 3.3. Numbers of hoverfly species per country in Europe (see Appendix A1).



3.1.3 Butterflies (Papilionoidea)

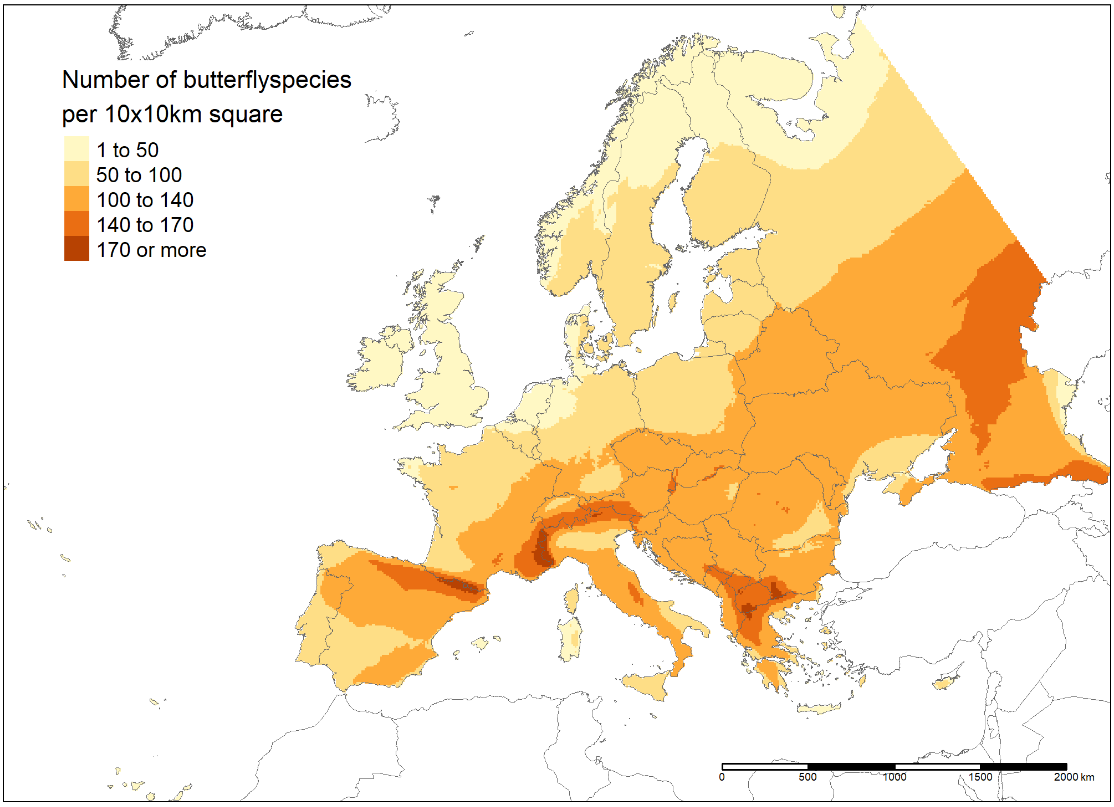
In Europe, there are 482 species of butterflies (Van Swaay *et al.*, 2010) divided into six families: the largest is the Nymphalidae, also called brush-footed butterflies, which are often large and brightly coloured species; the Lycaenidae are generally small brightly coloured butterflies, sometimes with a metallic sheen; the Pieridae have adults which are mainly white or yellow with black spots; the Hesperiidae typically display a rapid and speedy flight; and the Papilionidae, or swallowtail butterflies. The greatest diversity of butterflies is found in mountainous areas in the south of Europe, specifically the Cantabrian Mountains, the Pyrenees, the Alps, the Apennines, the Dinaric Alps, the Carpathians and the mountains of the Balkans (Figure 3.4).

Almost a third of butterfly species (142 species) are unique to Europe and are not found anywhere else in the world. The highest concentrations of endangered butterfly species are found in central and eastern Europe (Figure 3.5). The top five EU countries in terms of butterfly species richness (in descending order) are: Italy, France, Spain, Greece and Bulgaria.

3.1.4 Moths (all European Lepidoptera which are not Papilionoidea)

Moths are a very diverse group, with over 8,000 species in Europe (Karsholt & Razowski 1996); most of these are nocturnal, but diurnal and crepuscular species also occur. Many aspects of this large group are still poorly understood and their importance as pollinators remains largely unknown. Many pollinator studies focus on honey bees and bumble bees, likely because individual bee species have a relatively large contribution to pollination (Walton et al., 2020). However, the high abundance and diversity of moths potentially makes them an important complementary component to diurnal pollination (Walton et al., 2020). Recent studies suggest that moths play a large role in the pollination of wild flowers (Hahn & Brühl, 2016; Macgregor et al., 2019; VanZandt et al., 2020) and may contribute to crop pollination in agricultural systems although their contribution is likely non-essential (Hahn & Brühl, 2016).

Figure 3.4. Species richness of European butterflies (based on Van Swaay et al. 2010).



3.1.5 Other pollinator groups

In Europe, there are 58 families of beetles (Coleoptera) with almost 29,000 species. Some groups such as saproxylic beetles (~4,000 species in Europe) play an important role in decomposition and nutrient cycling, and many are also involved in pollination (Nieto and Alexander 2010). Some hairy flower-visiting beetles, such as chafers (*Amphimallon* spp.), can also be pollinators, but they often damage the floral reproductive structures so that no fruit or seed can form. In addition to bees, some other Hymenoptera, including wasps (Apocrita excluding ants and bees), sawflies (Symphyta), and ants (Formicidae) are common flower visitors and can also be pollinators. Non-syrphid flies (Diptera) comprise a large and diverse group of flying insects and are often seen on flowers; however, the proportion of these species that are actually pollinators is unknown.

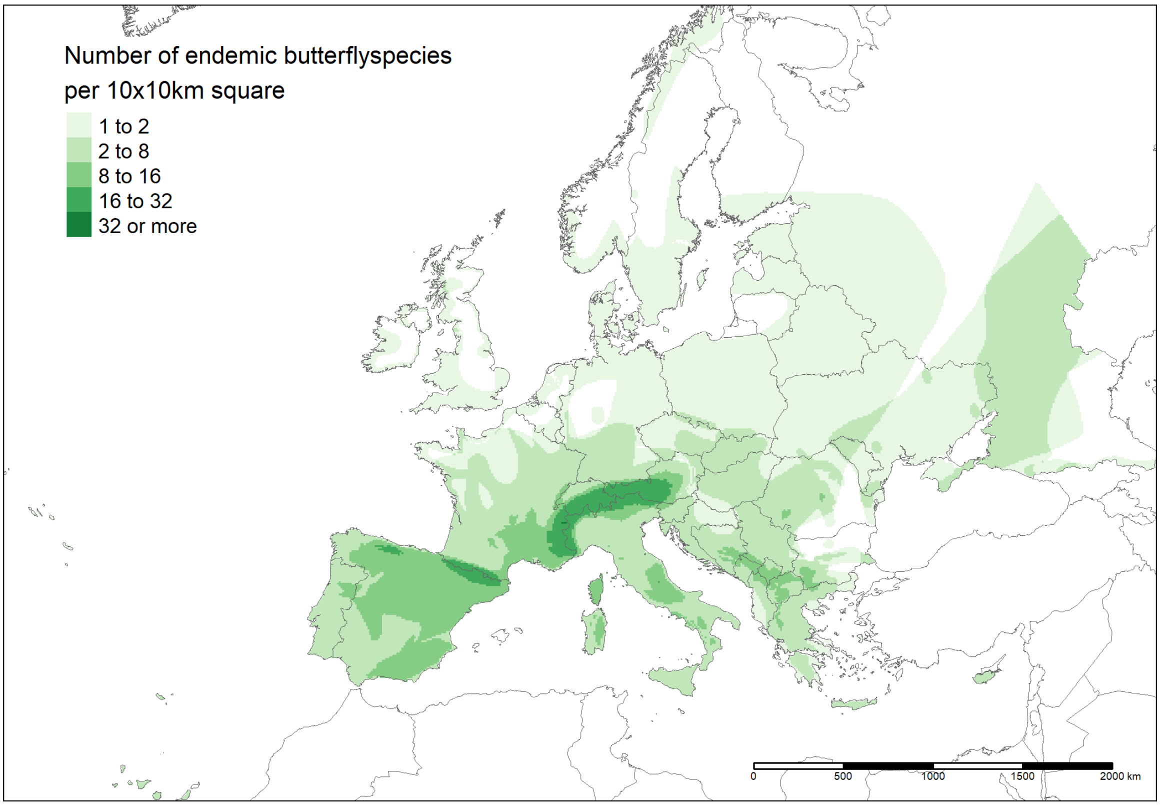
The proportion of these other insect groups that act as crop and wild flower pollinators is comparatively less studied than for the other groups described above. However, non-bee insects have been shown to be important pollinators of some crops (e.g. Rader et al. 2016).

3.2 Rationale for taxonomic group and measure selection

3.2.1 Approach to selection of taxonomic groups and measures

Europe supports a wide diversity of insect pollinators across many different taxonomic groups (section 3.1). While the proposed EU monitoring scheme aims to capture a very broad and representative part of this total pollinator biodiversity, it cannot target all pollinators. Therefore the expert group at their first meeting assessed multiple criteria in two independent break-out groups, followed by a consensus-building discussion with all experts, to prioritise those taxa which should be: (i) core groups included in the proposed Minimum Viable Scheme (MVS, see Figure 0.1); (ii) groups which should be included as modular add-ons to the MVS; and (iii) groups which require a fundamentally different approach to monitoring. The main criteria discussed by the expert groups included: proportion of a taxonomic group which are known pollinators or flower visitors, importance of contribution to crop and wild flower pollination, representativeness of wider biodiversity, vulnerability to environmental change, and conservation status. Additional considerations were also explored, such as potential feasibility for wide-scale monitoring, suitability of current and future methods, and taxonomic capacity for identifying species within a group; however, these criteria were not the prime ones used in proposing the priority list. The expert group recognised that there were considerable knowledge gaps around some of the above criteria for some taxa, but made their prioritisation on the best available evidence and knowledge at the time.

Figure 3.5. Distribution of endemic butterfly species in Europe (based on Van Swaay et al. 2010).



3.2.2 Taxonomic groups included in the core EU pollinator monitoring scheme

3.2.2.1 Taxonomic groups included in the Minimum Viable Scheme

The expert consensus was to include the three taxonomic groups in the Minimum Viable Scheme (Figure 0.1 and section 5.2) as they are feasible to implement in the short term, are major contributors to crop and wild plant pollination, and exhibit a huge diversity of life histories.

Bees (Anthophila): which include bumble bees and solitary bees (but not honey bees as these are being monitored through other approaches, see section 3.2.3). Europe has more than 2,000 species of wild bee which are widely recognised as one of the most important groups of crop and wild flower pollinators (Kleijn et al. 2016). As a group they exhibit a wide variety of contrasting life history traits: many species show high floral specialisation while others are much more generalists; they use a wide array of nesting substrates, such as bare ground, pithy stems, dead wood, disused rodent burrows, and artificial cavities; and they include many cuckoo species which are kleptoparasites of host bees (Michez et al. 2019). In the European Red List for bees, 9.2% of bees are assessed as threatened; however, more than half (56.7%) had insufficient scientific information to evaluate their risk of extinction (i.e. were Data Deficient); when additional data become available, it is expected that many of these data deficient species may also be threatened (Nieto et al. 2014).

Butterflies (Papilionoidea): These are one of the best studied insect groups in Europe with a number of well developed (and planned) national monitoring schemes already in place (see section 1.2.2). There are 482 butterfly species documented in Europe with almost a third of these endemic to Europe; about 9% of European butterflies are threatened in Europe while 10% are considered Near Threatened (Van Swaay et al. 2010). The life history of this group is highly dependent on the food plant of the caterpillars, with many species being highly specialised (Tolman 2002). While in Europe they make only a very small contribution to crop pollination, their role in wild flower pollination may be more important. Butterflies are also considered potentially useful biodiversity indicators (Van Swaay et al. 2010).

Hoverflies (Syrphidae): These are some of the most abundant and conspicuous Dipteran species found across Europe, with around 979 hoverfly species documented (Speight 2020). While adults primarily feed on pollen and nectar, larvae exhibit a diversity of feeding modes, including mycophagy, phytophagy, saprophagy and entomophagy (Thompson & Rotheray 1998). Adult hoverflies are considered important pollinators of both crops and wild flowers. A European Red List is currently in development and expected in 2021.

3.2.2.2 Groups included in the Core Scheme as Complementary Approaches

In addition to the three taxonomic groups in the MVS, two groups were proposed as part of the Core Scheme complementing the MVS (Figure 0.1 and section 5.3). Moths are not yet ready to be rolled out as part of the MVS, but with some further field validation and methodological refinement it could potentially be part of the MVS in the near future. Rare and threatened species were identified as a critical part of pollinator biodiversity to monitor, but as they require a fundamentally different approach to large-scale standardised monitoring they are included in a dedicated complementary module.

Moths (all European Lepidoptera which are not Papilionoidea): these are a very diverse group, with an estimated 8,026 species in Europe (Karsholt & Razowski 1996). Unlike butterflies, many species are nocturnal (there are also crepuscular and diurnal species), and so require a very different sampling method, such as light trapping or sugar baiting, to monitor them (sections 4.2.2 and 4.3.5). They are also documented as important pollinators of many wild flower species (Macgregor et al. 2015, Hahn & Brühl 2016, Macgregor et al. 2019, VanZandt et al. 2020. Walton et al. 2020), and they may contribute to crop pollination, although they are unlikely to be essential (Hahn & Brühl 2016). Full details on an additional 'Moth' module are given in section 5.3.1.

Rare and threatened species. Within all pollinator taxa there are some species which are (extremely) rare, very geographically localised, some of which may also be highly specialist in terms of habitat or flower use. A standardised, large-scale pan-European pollinator monitoring scheme is therefore extremely unlikely to sample these species sufficiently frequently to be able to detect any meaningful changes in their status. Consequently, different surveying and monitoring approaches are needed, which are often tailored to the specific ecology and biology of the target species. The proposed MVS will, however, sample many of the more common and widespread species of conservation concern, but these additional targeted methods are needed to complement this. Full details on monitoring 'Rare and threatened species' are given in section 5.3.2.

3.2.3 Taxonomic groups and measures included as additional modules

In addition to bees, butterflies, hoverflies, and moths, the expert group identified other taxonomic groups and measures which could also be important to monitor through additional modules (Figure 0.1 and section 5.4) to the core EU pollinator monitoring scheme. Their inclusion would build on to the Core Scheme infrastructure, and could be adopted where national interest, expertise, funding or existing monitoring programmes are present (see section 5.4 for details).

Wider insect biodiversity (Insecta): In addition to the taxa mentioned above, there are many other groups of flying insect within which some proportion of the species may also be pollinators. These include other flies (in addition to hoverflies), wasps, sawflies, bugs,


Oedemera flavipes, Axel Hochkirch

and beetles amongst other groups. Together, these groups comprise a huge number of species with very diverse life histories, habitat use, feeding types, reproductive modes and behaviours. They encompass a wide element of pollinator biodiversity and can provide an estimate of abundance and biomass. There are methods to sample whole flying insect communities, such as Malaise traps; however, specific methodological, practical and taxonomic challenges currently preclude this approach from the core monitoring scheme (section 4.3.4). Malaise traps could be used to monitor other aspects of biodiversity such as total flying insect biomass, non-pollinating insects, as well as pollinating insects, and full details on an additional 'Wider insect biodiversity' module are given in section 5.4.3.

Flower visitor counts. Floral visitation was identified as an important component of plant-pollinator biodiversity and should be included as a module in the wider scheme (see section 5.4.2). Flower visitors comprise a very diverse array of taxa, including all those in the Core Scheme.

Pollination services. The pollination of crops and wild flowers can be provided by a wide range of taxa, including those in the Core Scheme. Monitoring visitors can be used as an indirect proxy or pollination; however, a more direct measure of pollination services requires specialist methods to assess the biotic contribution to plant production/reproduction and does not require a direct assessment of the taxa responsible for the function/service (see section 5.4.1).

3.2.4 Taxonomic groups not included in the EU-PoMS

Honey bees (*Apis mellifera*). Honey bees make important contributions to crop and wild flower pollination, are the focal taxon of several large scale projects and initiatives, and so are not specifically included in the proposed pollinator monitoring scheme. However, they will be sampled by some of the EU-PoMS methods (e.g. pan traps). Examples of honey bee and honey bee health monitoring include:

- **PoshBee:** Pan-European assessment, monitoring, and mitigation of stressors on the health of bees. This project is assessing the effects of pesticides, pathogens and nutrition on the health of managed honey bees, bumble bees and solitary bees[1].
- **MUST-B:** Aims to develop a holistic approach to the risk assessment of multiple stressors in honey bees[2].
- **B-GOOD:** Aims to merge data from within and around beehives as well as wider socioeconomic conditions to develop and test innovative tools to perform risk assessments according to the Health Status Index (HSI)[3].

1 http://www.poshbee.eu
2 www.efsa.europa.eu/en/topics/topic/bee-health
3 https://b-good-project.eu

Andrena cineraria, Lill Dunne

3.2.5 Proposed measures to be included in the pollinator monitoring scheme

- As part of the process to prioritise taxa for the EU pollinator monitoring scheme, the range of measures were also critically assessed by the expert group. The consensus was to include the following measures:

- **Diversity:** including species richness, species diversity, and functional diversity (see sections 5.1 and 5.2).

- **Abundance:** including the abundance of wider taxonomic groups and abundance of individual species wherever possible (see sections 5.1 and 5.2).

- **Floral resources and habitats:** both at the point of sampling and wider landscape context (see sections 5.2.2).

- **Flower visitation:** through a specific add-on module which can assess group or species level visitation of wild flowers or crops (see section 5.4.2).

- **Pollination services:** Not all flower visitors are pollinators and not all species within a taxonomic group are pollinators either. Therefore pollination service needs to be measured either indirectly as a species or functional group visitation of crops flowers, or directly as the contribution of biotic pollination to crop production. An additional module for pollination services is presented in section 5.4.1, and development of a pollination service indicator is discussed in section 6.2.

- **Environmental drivers and pressures:** while not directly measured by the EU-PoMS, there are a range of existing driver and pressure indicators linked to land use change, climate change, pollution, and invasive species which are potentially highly relevant to pollinators and are reviewed in section 6.1.4.

References

Ascher JS and Pickering J (2020) Discover Life bee species guide and world checklist (Hymenoptera: Apoidea: Anthophila). http://www.discoverlife.org/mp/20q?guide=Apoidea_species

Bugg RL (1992) - Habitat manipulation to enhance the effectiveness of aphidophagous hover flies (Diptera: Syrphidae). Sustainable Agriculture, University of California, 1992.

Hahn M & Brühl CA (2016) The secret pollinators: an overview of moth pollination with a focus on Europe and North America. *Arthropod-Plant Interactions*, *10* (1), 21-28.

Karsholt O & Razowski J (Eds). (1996) *The Lepidoptera of Europe: a distributional checklist.* Brill Academic Pub.

Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein A-M, … Potts SG (2015) Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 6: 7414.

Loïc Matile. 1993 - Les Diptères d'E Western Europe. Tome I: Introduction, Techniques d'étude et Morphologie. Nématocères, Brachycères Orthorrhaphes et Aschizes. Paris, Boubée.

Macgregor CJ, Kitson JJ, Fox R, Hahn C, Lunt DH, Pocock MJ, & Evans DM (2019) Construction, validation, and application of nocturnal pollen transport networks in an agro-ecosystem: a comparison using light microscopy and DNA metabarcoding. *Ecological entomology*, *44*(1), 17-29.

Macgregor CJ, Williams JH, Bell JR, & Thomas CD (2019) Moth biomass increases and decreases over 50 years in Britain. *Nature Ecology & Evolution*, *3*(12), 1645–1649.

Macgregor CJ, Pocock MJ, Fox R, & Evans DM (2015) Pollination by nocturnal Lepidoptera, and the effects of light pollution: a review. *Ecological entomology*, *40* (3), 187-198.

Michez D, Rasmont P, Terzo M, Vereecken NJ (2019) Bees of Europe. NAP Editions. 548 pp.

Nieto A and Alexander KNA. (2010) European Red List of saproxylic beetles. Luxembourg: Publications Office of the European Union.

Nieto A, Roberts SPM, Kemp J, Rasmont P, Kuhlmann M, … Michez D (2014) European Red List of Bees. Luxembourg: Publication Office of the European Union

Rasmont P, Devalez J, Pauly A, Michez D, Radchenko VG (2017) Addition to the checklist of IUCN European wild bees (Hymenoptera: Apoidea), Annales de la Société entomologique de France (N.S.), 53:1, 17-32 Radchenko G. (2017) Addition to the checklist of IUCN European wild bees (Hymenoptera: Apoidea), Annales de la Société entomologique de France (N.S.), 53: 1, 17-32, DOI: https://doi.org/10.1080/00379271.2017.1307696

Rader R, Bartomeus I, Garibaldi LA, Garratt MPD, Howlett B, Winfree R … Woyciechowski M (2016) Non-bee insects are important contributors to global crop pollination. Proceedings of the National Academy of Sciences 113: 146-151

Speight MCD (2017) Species accounts of European Syrphidae. Syrph the Net, the database of European Syrphidae (Diptera) 97: 294 pp.

Speight MCD, Castella E & Sarthou JP (2020) StN 2020. In: Syrph the Net on CD, Issue 12. Speight, M.C.D., Castella, E., Sarthou, J.-P. & Vanappelghem, C (Eds) ISSN 1649-1917. Syrph the Net Publications, Dublin.

Thompson FC, Rotheray G (1998) Family Syrphidae. In: Papp L, Darvas B (eds): Manual of Palaearctic Diptera. Vol 3. Science Herald, Budapest: 81-139.

Tolman T (2002) Butterflies of Europe. Princeton Field Guides

Van Swaay C, Cuttelod A, Collins S, Maes D, López Munguira M, Šašić M, Settele J, Verovnik R, Verstrael T, Warren M, Wiemers M and Wynhof I (2010) European Red List of Butterflies. Luxembourg: Publication Office of the European Union

VanZandt PA, Johnson DD, Hartley C, LeCroy KA, Shew HW, Davis BT, & Lehnert MS (2020) Which moths might be pollinators? Approaches in the search for the flower-visiting needles in the Lepidopteran haystack. *Ecological Entomology*.

Vujić A, Speight M, de Courcy Williams ME, Rojo S, Ståhls G, Radenković S, Likov L, Miličić M, Pérez-Bañón C, Falk S, Petanidou T (2020) Atlas of the Hoverflies of Greece (Diptera: Syrphidae). Leiden, Brill, 384 pp. https://doi.org/10.1163/9789004334670

Walton RE, Sayer CD, Bennion H, Axmacher JC (2020) Nocturnal pollinators strongly contribute to pollen transport of wild flowers in an agricultural landscape. Biol. Lett. 16: 20190877

4 Selection of Methods for the EU Pollinator Monitoring Scheme

There is a wide range of different methods for sampling pollinators and no single one is ideal, as all methods have limitations. Hence a combination of Complementary Approaches is likely to be most effective. In this chapter, we describe a variety of methods in detail and assess their advantages and disadvantages. Methods documented in this chapter are listed under different categories of targeted insect behaviour: searching for nectar or pollen (section 4.2), flying (section 4.3), resting (section 4.4) and breeding or overwintering (section 4.5). A summary of attributes of the different methods is given in Appendix 4.1. Our rationale and recommendations for methods to adopt as part of an EU Pollinator Monitoring Scheme are given in section 4.6.

4.1 Approach to assessing the advantages and disadvantages of different methods

The two broad approaches to biodiversity sampling are passive and active sampling. Active methods, such as pan traps or bait traps, attract insects to the trap. These tend to capture larger samples, but because they are partially based on attraction, the results can be hard to interpret; in contrast, passive methods (e.g. Malaise traps or transect walks) do not rely on attracting insects and can provide area-based measures, although their capture rates are usually relatively low (Muirhead-Thompson, 2012; Weissling & Knight, 1994).

Collecting pollinators by sweep net, Snežana Popov

In addition to the choice of methods, consideration of who is going to collect the data is vital, as all methods that depend upon volunteers to select sites have the potential for an unbalanced spatial distribution. Volunteer-selected sampling locations tend to be biased towards those habitats or landscapes with a high diversity and/or abundance of the target taxa. Depending upon the sampling design, the data may have to be supplemented with additional representative sampling sites using paid personnel (section 5.2). It will also be easier to find volunteers for some methods (Garratt et al., 2019); for example, it would likely be easier to find volunteers for a butterfly transect walk, than for a Malaise trap, where dead insects have to be collected regularly and sent away to a lab for analysis. A major disadvantage of working with volunteers is the relatively large observational bias, caused by a wide range of observation skills among them.

We discuss methods that depend on either lethal or non-lethal sampling. It is important to realise that lethal sampling is generally more expensive, as captured specimens have to be processed. However, lethal sampling has the potential to provide additional data from the specimens, such as pollen analyses and DNA studies, which can yield much more information when samples are stored and processed again at a later date.

Throughout this Chapter, cost estimates are presented based only on the material costs of implementing the method and the costs of identifying, storing and, for lethal methods only, sorting specimens. They do not include any costs that are related to the structure of a monitoring scheme, such as professional labour costs, fuel costs from travelling to sites, identification materials or other training for staff or volunteers, feedback, dissemination, websites or administrative staff salaries. The costs presented here are rough indications; they are assessed in depth in Section 5.5.

4.2 Methods targeting foraging insects

The following methods are focused on insects that are actively searching for nectar or pollen. When looking at pollinators, sampling insects that search for nectar or pollen is often effective.

4.2.1 Flower visitors counts

Description

Timed focal plant observations are widely used in studies on plant-pollinator interactions and offer a way of monitoring the abundance of flower-visiting insects. A standardised quadrat is observed for a short period and insects who visit a defined flower species are counted. Selecting target flowers from a defined list of common plant species can help to standardise observations. For a non-flower oriented version of the flower visitor counts, see section 4.3.3.

Scope

A standardised plot, containing flowers visited by pollinators is observed for a short period (Figure 4.1). Recent studies on the design and testing of a National Pollinator and Pollination Monitoring Framework in the UK (Carvell et al., 2016) reviewed it as a method and it has been adopted within the UK Pollinator Monitoring Scheme (PoMS, section 1.2.3) as Flower Insect Timed (FIT) counts. In the UK and Ireland, it is operated under a citizen science model. A 50 x 50cm patch of flowers is observed for 10 minutes and the number of insects who visit the target flowers is recorded. It does not typically provide species level data of the pollinators, but rather information on abundance at insect group level. It potentially offers an accessible approach to generating data on abundance and visitation rates, at least to group level. In the UK and Ireland, ten categories are used at the insect group level: honey bees, bumble bees, solitary bees, wasps (including ichneumon wasps), hoverflies (including 'non-typical' hoverflies), other flies, butterflies and moths, beetles (larger than 3 mm), small insects (such as pollen beetles) less than 3 mm long, and other insects. In both the UK and Irish schemes, 14 focal plant species are on the target list, and volunteers are encouraged to observe these species, although they can also observe any other flower species that is attracting insects. Counts take place between the beginning of April and the end of September, under defined weather conditions. In the citizen science scheme, any location can be used. Volunteers are asked to provide additional information on their location, weather conditions, and number of target flowers. They are encouraged to carry out repeat counts at the same location (or very close-by), using different flowers at different times of year.

Requirements

The only equipment needed is a quadrat and the volunteers themselves can make this. This method is relatively easy to participate in and volunteers require little to no training, although offering training material can improve the data quality. Such a method requires the development of basic resources for some sort of central coordination and ideally an online data submission system. In the UK and Ireland, it is currently operated as a citizen science initiative, and in the UK, it is also a component of a wider sampling protocol implemented on the sites included within the UK Pollinator Monitoring Scheme (section 1.2.3).

Figure 4.1. An example of using a quadrat with Dandelions (*Taraxacum officinale*) as the target flower. Picture by Úna FitzPatrick.

Using a quadrat with Dandelion as the target flower. This quadrat has 3 flowers (discounting those that have gone to seed)

Costs

If records are not verified, there are no costs associated with this method. Photographic verification of specimens to a coarse taxonomic resolution would cost ~€5 in technician time to validate.

Advantages

This is a very low-cost method as it can be largely based on volunteers. It is a non-lethal technique, and it is easy to carry out with little effort required, which means it can attract a much wider volunteer pool than other surveys that require greater levels of expertise. The data can be submitted directly online so it is quickly available. It is also a good way to engage the wider public in data collection and is useful for taking advantage of the current public interest in the plight of pollinators.

Disadvantages

This method only collects data on broad insect groups (e.g. bumble bees, hoverflies, other flies etc.). If operated under a citizen science model, data generation can be spatially quite random (sampling can be carried out in any location at any time under suitable weather conditions). It works best when volunteers focus on, or are encouraged to target, specific common flowers, but this can be difficult within a citizen science framework. This method is probably most effective as one component (e.g. as an entry level) within a wider suite of methodologies which come together to form a wider pollinator monitoring protocol (as is the case in the UK).

Examples

Other schemes have used a similar approach e.g., Big Discovery in the UK (Roy et al., 2016). This method is currently used in the UK Pollinator Monitoring Scheme[1] and has been operating in Ireland since May 2019[2].

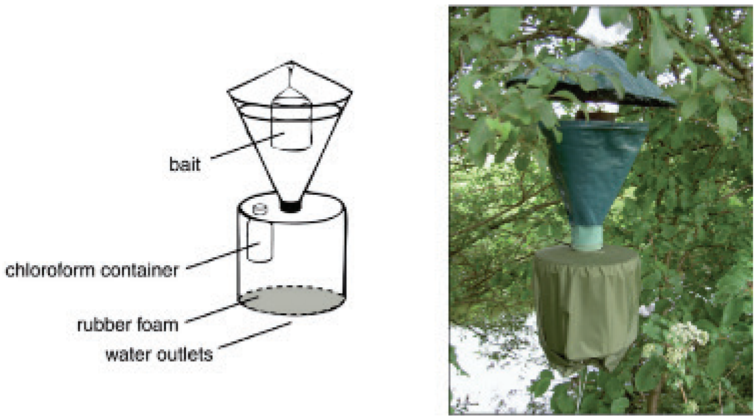
4.2.2 Sugar bait traps

Description

Sugar bait traps (Figure 4.2) attract noctuid and geometrid moths and can be used in all seasons from spring to autumn (Pettersson & Franzén, 2008; Söderman, 1994). They resemble light traps (section 4.3.5) in their construction but are generally smaller in size. Instead of a lamp, a hanging bait container is used. The bait container consists of a small cup into which a piece of foam is placed. A bait solution is then poured into the cup, and the liquid is drawn into the foam piece. There is little standardisation in the type of bait used but the most common solutions are made by either dissolving brown sugar into beer and adding yeast, or by mixing equal parts of white sugar and red wine. Recipes can be found in Pettersson and Franzén (2008). Chloroform is generally used as a killing agent (Pettersson & Franzén, 2008; Söderman, 1994; Várkonyi et al., 2003).

1 https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring
2 https://pollinators.ie/record-pollinators/fit-count/

Figure 4.2. An example of a sugar bait trap design used to sample moths. Picture from Pettersson and Franzén (2008).



Scope

Sugar bait traps attract many species of large moths, particularly noctuids, but also some geometrid species. In addition, bait traps may attract nymphalid butterflies (especially Red Admirals, *Vanessa atalanta*). The method is based on attracting insects that are looking for aphid honeydew or rotting fruits to feed on. The number of species typically attracted by bait traps is substantially lower than those attracted by light traps, and these two methods complement each other because bait traps attract some noctuid species that are not attracted by light. The effectiveness of bait traps varies between seasons; especially in the spring moths appear to be less attracted to sugar baits. Although currently not often used for multi-year monitoring, there is potential for large-scale trapping schemes to run over multiple years.

Requirements

A sugar bait trapping method has been developed in Finland (Pettersson & Franzén, 2008; Söderman, 1994), where Jalas-type bait traps are commercially available. In Jalas traps, attracted insects fall into a sample container where they remain until the trap is checked. Traps need to be secured against wind action to avoid bait pouring into the lower compartment. Sugar bait traps also need to be emptied and sugar bait solution added once every 1-2 weeks, if a killing agent (e.g. chloroform) is placed in the trap. Field workers need to be made aware of the risks of working with chloroform, as it poses a health risk to humans. Ethyl acetate can also be used as a killing agent, although it evaporates relatively quickly, and hence traps cannot be left out for longer than one night at a time. If no killing agent is used and the moths are to be released alive after recording the species, daily checking is necessary (Várkonyi et al., 2003). Identification of moths caught by sugar bait trapping is relatively easy for volunteers with little training, but the longer the traps are deployed, the more demanding identification work becomes as the colours of captured specimens start to fade.

Costs

Sugar bait traps are relatively cheap and are commercially available for entomologists in Finland via the Finnish Lepidopterological Society. Additional costs are the bait solution and a killing agent if samples are killed. Moths can potentially be identified by volunteers, although the availability of volunteers to identify dead moths is likely to differ between countries (Chapter 7). Up to about 10% are likely to require professional identification. In total, the estimated cost would be ~€25/round, assuming 3 traps per site and 4 rounds per year.

Advantages

As no electricity is needed, sugar bait traps are easier to place than light traps. Another advantage over light traps is that they work in high latitudes where light trapping is much less effective during bright summer nights. Additionally, as these bait traps are relatively inexpensive, a large number can be deployed, allowing for well replicated designs. Bait traps attract a different set of noctuid species compared to light traps, as not all these species are attracted to light.

Disadvantages

Attractiveness of sugar baits varies between seasons, and it is generally lower during spring. Sugar baits attract smaller number of species than light traps. This method mainly attracts moths; other pollinator groups are not especially attracted by this technique and not all moths are attracted by sugar bait. The need for a killing agent and the use of a sugary solution in the trap makes them more demanding to operate than light traps. Standardisation of the trap design and bait composition need further development, and using chloroform as a killing agent can cause a health risk. Placement height can cause a potential bias, and should be standardised.

Examples

Although sugar bait traps are increasingly used in in moth species surveys (Laaksonen et al., 2006; Pettersson & Franzén, 2008) and in ecological studies of moths (Mönkkönen & Mutanen, 2003; Várkonyi et al., 2003) in Nordic countries, there seem to be no monitoring schemes currently running based on sugar bait traps (but see: Itämies et al., 2011). One probable reason for this is that these traps are more demanding to operate than their light trap counterparts.

4.2.3 Russell yellow traps

Description

A Russell yellow trap (Figure 4.3) attracts day-active pollinators (particularly bumble bees) through its yellow colour, especially during spring and autumn when wild flowers are scarce (Paukkunen et al., 2008; Söderman, 1999; Söderman et al., 1997), which occurs in midsummer in the Mediterranean. These traps are commercially available (e.g. Russell Chemicals Technology Co., Ltd) and were originally designed to be used as pheromone traps for attracting insect pests. To attract pollinators, the traps are usually placed 0.5 to 1 metre above the ground or above the basal vegetation. It is usually recommended to place the traps in clusters of three with 5 to 10 m spacing, as there is often much variation in the attraction efficiency of individual trap locations within one sampling area.

Figure 4.3. An example of a Russell yellow trap used to trap day-active pollinators. Pictures from Paukkunen et al., (2008) and Söderman (1999).

Scope

The traps are often especially effective for attracting bumble bees and in surveying their species richness during the spring. The efficiency of the traps decreases substantially during the summer when natural flowers become more available, making the traps relatively less attractive compared to the background habitat. In addition to bumble bees the traps can attract smaller numbers of solitary bees and other flower-visiting insects; the number of hoverflies in the traps typically increases towards late summer. (Monsevičius, 2004; Söderman, 1999). A similar trap (but without the roof) is available in blue, known as a blue vane trap.

Requirements

A strip of DDVP (dichlorvos, or sometimes commonly called Vapona) is placed in the sample container and acts as a killing agent. One DDVP strip is effective throughout a season. The traps need to be checked in approximately 2-week intervals. Pollinator samples usually remain in the traps in good condition for identification as the green-coloured roof prevents rain from entering the trap. Experts are needed for identification of pollinator samples, and identification can be conducted during winter if the samples are frozen after capture.

Costs

The Russell yellow traps themselves (also known as "Mothcatcher" traps by Russell Chemicals Technology Co., Ltd) are commercially available and relatively cheap. At least three traps are required in each sampling site. Additional costs arise from DDVP strips, and potentially also from regular checking of traps and expert identification of (a portion) samples if volunteers are not available. In total, these costs (when working with volunteers) are estimated as ~€18/round, ~€72/year.

Advantages

Fairly large samples of bumble bees can easily and simultaneously be collected from multiple locations. The traps are relatively effective for catching bumble bees during the spring and hoverflies, especially in late summer.

Disadvantages

Use of the method is destructive for bumble bee populations, because traps are most effective during spring when only bumble bee queens are active. The traps do not effectively sample solitary bees. Attraction efficiency of individual traps varies a lot and unpredictably between nearby trapping locations. Therefore at least three traps are required in one sampling site. This trap suffers from a problem shared by all traps in that they attract insects by colour and so its effectiveness depends upon its surroundings. When placed in a flower rich environment the effectiveness decreases because it competes for the attention of insects with flowers (see also section 4.2.4 on pan trapping for a more extensive discussion on this topic). This is why it performs best in seasons without many flowers (Paukkunen et al., 2008; Söderman, 1999; Söderman et al., 1997).

Examples

Russell yellow traps were used in two pilot monitoring projects of pollinators in Finland, Eastern Fennoscandia and the Baltic countries during the years 1995-2005 (Kuussaari et al., 2008; Söderman, 1999; Söderman et al., 1997). After the first years of experience Söderman (1999) considered the method as a promising tool for pollinator monitoring. However, results from five consecutive years of monitoring in 10 localities suggested that the annual use of the method in the same site was destructive for bumble bee populations (Paukkunen et al., 2008). Therefore, since 2005, these traps have no longer been used for monitoring in Finland. Paukkunen et al. (2008) concluded that the method could be useful to map changes in bumble bee occurrence and distribution e.g. in 10-year intervals, but that it is not suitable for continuous, annual monitoring of species abundances.

4.2.4 Pan traps

Description

Pan traps are a lethal sampling technique designed to survey foraging insects (Figure 4.4). Increasingly widely used since introduced by Kirk (1984), they are water-filled bowls (with some soap to break surface tension), typically of three colours set on stakes at vegetation height to mimic flowers, and collected after a specified duration. Pan traps allow for the assessment of the relative insect abundance in an environment and have been promoted by the Food and Agricultural Organization (FAO) as an efficient data collection methodology in monitoring pollinator communities (LeBuhn et al., 2016). The use of pan traps is strongly debated in scientific literature; several studies have found that pan trapping can outperform other methods such as transect walks by catching more individuals and more species (Nielsen et al., 2011; Westphal et al., 2008). However, critics point out that these studies are based on a relatively high sampling intensity of clusters of 5 (Westphal et al., 2008) to 10 sets of traps (Nielsen et al., 2011) and hence for a fair comparison other techniques should also be replicated more often. This is not to deny that in these studies, numerously deployed pan traps seem to provide useful data. The possible problems with pan traps are well described in Cane et al. (2000), who noted that many common native bee species were not present in the pan traps, and that data produced by such did not represent the local community.

Scope

Pan traps are widely applied to sample bees and other insects, although they are known to perform poorly for some taxa (Wilson et al., 2008). Pan trapping can be particularly useful for sampling solitary bees and foraging hoverflies. This method can provide

Figure 4.4. An example of coloured pan traps used to survey foraging insects. Pictures by Úna FitzPatrick (left) and Saorla Kavanagh (right).

an indication of occupancy, and possibly an indication of abundance, though true abundance is difficult for all methods that rely on colour attraction as they can compete with flowers and hence their attraction (radius) changes throughout the season. The effect of flowers also increases the effect of immediate surroundings, decreasing the effect of the wider study area, which can make it difficult to compare between sites.

Recent studies during the design and testing of a National Pollinator and Pollination Monitoring Framework in the UK (Carvell et al., 2016) identified pan traps as an effective method of monitoring bees and hoverflies and they have since been adopted within the UK Pollinator Monitoring Scheme (PoMS, section 1.2.3). They found that at comparable levels of sampling effort (over similar temporal and spatial scales), pan traps sampled more species than transects, particularly for solitary bees and hoverflies. For solitary bees, pan traps prove particularly effective in capturing some of the smaller, less conspicuous species. Pan trapping is a lethal sampling approach, but studies suggest this has minor detrimental effects on local populations over time (Gezon et al., 2015).

Requirements

Trapping stations typically consist of three bowls (UV reflective blue, white and yellow) containing water and a drop of (unscented) detergent (to break surface tension) in which insects land and drown. They are often raised to vegetation height and exposed for a duration typically of 24 to 48hrs. The UK PoMS trials (Carvell et al., 2016) suggested that the duration traps which were left out in the field only slightly influenced total catch, with higher total abundance and species richness of bees and hoverflies over 48 hours, but no difference between 6-7 hour and 24-hour trapping periods. In the UK, trials of a 6-7 hour trapping duration provided data deemed to be of sufficient quality for quantitative analysis (Carvell et al., 2016). Results also showed that the number of bees caught was strongly influenced by the number of flowers surrounding a trap, and so data on floral resources should also be collected. The operation of pan traps does not require expert knowledge and can be readily implemented by volunteer networks (assuming they are comfortable with lethal sampling). Experts are needed for identification of pollinator samples. Samples need to be removed from traps and stored in ethanol, allowing identification to be done subsequently (e.g. during the winter).

Costs

Pan traps are relatively inexpensive and easy to make but can be costly to set up due to the labour required to set up, collect and remove multiple trapping stations across a site. Based on the UK's PoMS network (section 1.2.3), a typical pan trap site will require: 5 pan trap stations capable of holding 3 bowls each, UV reflective sprays (yellow, white and blue) to colour each triplet of bowels, a quantity of detergent (to break the surface tension of the water in bowls), a sieve and forceps to separate samples, and a mallet to set up the trap. Including two spare traps and three sets of triplets, this set-up would cost ~€82 and last for 5 years. This kit can also be reused between different sites by the same recorder. In addition, ~5 sampling tubes, muslin gauze and ~100 ml of ethanol would be required per visit, costing ~€5 in total per visit (or ~€21/year). Additionally, all specimens caught would require sorting and identification. Including these costs, the total costs are estimated to be ~€105/visit and ~€421/site/year (for a more detailed cost estimate see chapter 5.5.1.1).

Advantages

Pan trapping is an effective way to sample nectar or pollen searching insects (particularly smaller bee and hoverfly species). It provides quantitative data on the abundance of a large part of the wild bee fauna without the bias associated with the difference in capture efficiency among observers (Campbell & Hanula, 2007; Cane et al., 2000; Roulston et al., 2007; Toler et al., 2005; Westphal et al., 2008). The UK PoMS found that pan traps were more effective than transects when monitoring solitary bees. Pan traps can also pick up parasitic bee species, seldom caught on flowers, and provide a useful tool for augmenting other sampling techniques when there are few host plants to sample, such as in early spring (Roulston et al., 2007). Large numbers of samples can be easily and simultaneously collected from multiple locations. As the sampling itself does not require expert knowledge, it can potentially take advantage of citizen science networks.

Disadvantages

As a bee sampling technique, pan traps catch bumble bees, honey bees and larger genera such as *Colletes* less frequently than expected by their expected abundance (Monsevičius, 2004; Toler et al., 2005). Pan traps will also typically collect a subset of hoverflies, but they are likely to pick up those that are important pollinators. Pan trapping is very sensitive to the immediate floral environment (Dauber et al., 2003) and the effectiveness of pan traps is strongly related to the abundance of flowers in their surroundings (Baum & Wallen, 2011; Roulston et al., 2007) meaning that data on floral resources surrounding a trap should also be collected so that this can be used in any subsequent analysis, which can be time-consuming. Robust analyses are not yet available to provide confidence that flower data can adequately address this bias.

Techniques such as transects (sections 4.3.1 and 4.3.2) can be used to collect additional information on insect-plant interaction, and they provide an estimate of pollinator density (numbers per unit area), whereas the area sampled by a pan trap is highly context dependent and hard to ascertain. Pan trapping is unlikely to adequately monitor rare species (see section 5.3.2) or the more specialised pollinators of some native plant species unless targeted to sites or specialist habitats (e.g. using 'free search' approaches). It is a technique that requires experts for identification; leaving insects in the traps too long makes this identification process more difficult. It is always possible that pan traps can be disturbed or damaged in the field by people, livestock, by high winds or hailstorms, although a short (e.g. 1 day) sampling period can reduce this risk.

Examples

After a review of methods and dedicated field trials, pan trapping has been adopted as the core sampling technique in the UK Pollinator Monitoring Scheme (section 1.2.3). It is also recommended as a protocol to detect and monitor pollinators by the FAO (2016). Earlier examples of the approach in a monitoring context also exist; for instance in 2014 in the UK, members of the general public carried out monthly trapping for 48 hrs using three pan bowls in their garden[3] and a more intensive sampling approach in the US mid-Atlantic States was run by a combination of volunteers, county and state employees (Droege et al., 2010).

4.3 Methods targeting flying insects

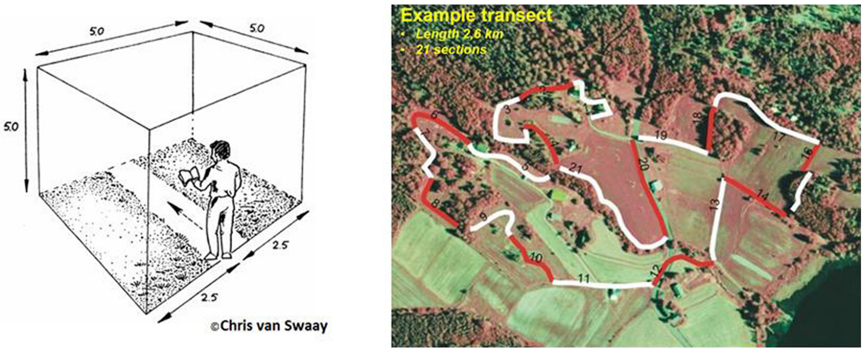
These methods focus on capturing or observing insects in flight. Although flight is important for pollination, not all flight is related to flower visitation.

4.3.1 Transect walks for butterflies

Description

This passive method focuses on butterflies and is also sometimes called a Pollard walk (Figure 4.5). Butterflies are typically counted along a 1 to 2 km fixed transect route, and ideally sampled once a week throughout the summer from spring to autumn (Pollard, 1977; Pollard & Yates, 1994; van Swaay et al., 2008). A surveyor walks along the transect at a steady speed and records every butterfly individual observed within an imaginary box 5 m ahead and 2.5 m on either side of the surveyor. Species that cannot be distinguished reliably in flight can be caught for identification, and then immediately released at the place of capture. Counts are only made in strictly defined weather conditions when butterflies are active, i.e. not too cold, cloudy or in windy weather. The length of the monitoring season varies between countries, but usually the number of sampling rounds varies between 7 and 20 during one season.

Figure 4.5. An example of a transect walk used to survey butterflies (white sections are counted, red sections are skipped). Pictures by Chris van Swaay and Janne Heliölä.



The method is well standardised and the same methodology is used in the butterfly monitoring schemes across Europe (section 1.2.2). The method can be used in all kinds of landscapes where butterflies occur, although care should be taken to ensure that the transect represents the local landscape well. Usually the transect routes are divided into subsections each of which consists of a relatively homogeneous habitat type. Thus, the method also produces habitat specific information on butterfly occurrence. The transect walk is suitable for monitoring most European butterfly species, although tree canopy-flying species are the most significant exception.

3 http://thebuzzclub.uk/citizen-science-projects/pollinator-abundance-network

An annual abundance estimate for each species is provided by combining results from all the counts of one season. More accurate annual abundance estimates can be calculated by taking into account species-specific annual flight curves (within the same geographic region) and by estimating abundances during missing weekly counts based on the observed annual flight curve (Dennis et al., 2013; Schmucki et al., 2016).

Scope

The method focuses on butterflies. It is possible to also count day-flying moths simultaneously, and they are counted in some of the transect routes in the monitoring schemes in Finland, UK and Ireland. Simultaneously counting other insects in addition to lepidopteran pollinators, such as bumble bees (see section 4.3.2), is more demanding. It can be feasible for experienced surveyors, especially if neither of the monitored insect groups is very abundant, but usually butterflies and bumble bees need separate counts on transects. Detectability of butterflies in transect counts varies between species (Isaac et al., 2011; Kery and Plattner, 2007). Isaac et al. (2011) estimated that around one third of individual butterflies were missed in 5 m wide transects. Nevertheless, they concluded that transect walks provide a good reflection of relative abundance for most species and of large-scale trends in annual abundance. All kinds of active butterflies are typically observed in transect counts (i.e. the method does not focus on any specific type of behaviour of butterflies). In some national schemes volunteers are also asked to record flower availability, which is known to have a large influence on the number of insects.

Requirements

Essentially, just a relevant identification book on butterflies and a butterfly net are needed. The butterfly net is needed to catch butterfly species that cannot be identified in flight. In most parts of Europe, identification of butterflies is feasible for volunteers with training, although this can vary greatly between countries. The transect route and its numbered subsections should be drawn on a map. In the field the daily butterfly count results, together with some weather information, are either written down on an observation sheet or electronically saved using a relevant mobile app.

Costs

The method is relatively cheap if skilled volunteers are available for counting butterflies. Potential costs include a butterfly net and a butterfly identification guide, although most volunteers are likely to already have these. This method does not have any costs per visit if no specimens are caught. If expert identification is required for captured specimens, this method costs approximately ~€21 if conducted by experts, who can be expected to catch more specimens (excluding salaries), and ~€19 if conducted by volunteers (see section 5.5.1.2).

Advantages

Standardised transect counts for butterflies have proven to be a cost-effective monitoring method that works well based on volunteers conducting the field work. It has a well-established methodology that has been tested in various ways in a number of published studies (e.g. Isaac et al. 2011). In recent years there has been progress in combining results from several schemes that are running in different countries based on the same methodology, and currently eBMS[4] (section 1.2.2) provides a model on how a European-wide biodiversity monitoring partnership can work in practice. An additional advantage of this method is the availability of an established infrastructure to support butterfly monitoring as well as guidance documents translated into multiple languages.

An important strength of the method is that no samples (and killing of insects) are needed which is appealing for the volunteers participating in the monitoring, and also speeds up the processing of results so that annual results can be published with just a minimal time delay. Additionally this method can be used to estimate densities (individuals per area), which is important if results are extrapolated to a larger spatial scale.

Disadvantages

This method covers only butterflies and not the other, more economically important, pollinator groups. There can be a strong observation bias, as highly skilled observers will see more than normal observers will. There is a potential for counting individuals more than once, although statistical techniques are available to deal with this bias.

Examples

National monitoring schemes based on this method already exist in many European countries (section 1.2.2). Several countries have an established annual reporting procedures. Several of the longer running national schemes have published their results in a number of scientific papers (especially from the UK, the Netherlands and Catalonia). In addition, there is strong European level collaboration between countries (eBMS). For example, eBMS, collates national butterfly monitoring scheme datasets within Europe into a central database. Scientific papers with novel European-wide perspectives have been published based on combining monitoring datasets from different countries (e.g. Devictor et al., 2012; Schmucki et al., 2016). The active European level collaboration of schemes is leading to more and more standardised procedures in both monitoring and reporting of the results in different countries. The ongoing ABLE project (section 1.2.2) aims to further help in achieving such targets.

4.3.2 Transect walks for other pollinators

Description

The transect walk method that has been widely used in butterflies (section 4.3.1) is also potentially suitable for monitoring the abundance of other pollinators. Species such as bumble bees (Matechou et al., 2018), solitary bees (Woodcock et al., 2013) or hoverflies (Ekroos et al., 2013) can be counted using similar methods as the butterfly transects (section 4.3.1).

A surveyor walks along the transect route at a steady speed and records every individual of the target species group (e.g. butterflies or bumble bees) observed within a transect route of constant width ahead and to the side of the surveyor. Ideally, the individuals are identified to species and also to caste (i.e. queen, worker, male) where possible. When a species cannot be identified, they can be caught and brought to the lab for identification. Optionally, all encountered species can be caught and brought to the lab for identification. This is often done for species that are difficult to identify such as solitary bees or hover flies (e.g. Ekroos et al., 2013).

Currently the width of transect walk recording varies between different monitoring schemes and can be between 2 and 5 m. Counts are only made in weather conditions that allow the target species to be active. This is often defined as a min-max temperature, a maximum windiness and cloudiness and no or very little rain. The exact conditions differ between schemes, target species and applications. The length of the monitoring season varies depending on the species and differs between countries, but is typically between 5 and 15 visits in one season. This method can be used in almost all landscape types. An annual abundance estimate for each species is obtained by combining results from all the counts.

4 https://butterfly-monitoring.net/ebms

When compared with other sampling methods this method represents the pollinators of an area well, and although at most study sites pan traps capture more individuals than transect walks, the latter overall detected the highest species richness for bumble bees (Nielsen et al., 2011). Westphal noted that transect walks generally detect many species and individuals but have a significant observer bias (Westphal et al., 2008).

Scope

The method can be used to count several groups of pollinators, e.g. bumble bees, solitary bees and hover flies. But identification to species level is not realistic for many of these groups. Identification of most butterfly or bumble bee species is possible by volunteers with a small amount of training. However, in most European countries there are species pairs or groups with similarly coloured morphotypes that cannot be identified to species level in the field. For solitary bees and hoverflies identification to species level in the field is even more difficult and often not even feasible for experts. For these groups all specimens should be caught and identified in the lab. As with the butterfly transects, the flower availability is important to insect occurrence, and can be recorded to improve data quality. This emphasises the importance of proper placement in the landscape; it is absolutely vital that the transects are placed to represent the (local) landscape.

Requirements

This method requires a net, and depending on the approach, a relevant identification guide or material to store captured species.

Costs

If skilled volunteers are available, this method can be relatively cheap. In this case potential costs include a net and an identification guide, although volunteers are likely to have these already. This method has no costs per visit unless unidentified species are caught and sent to an expert for identification, in which case the costs are similar to the butterfly transects, i.e. ~€21 for professionals and ~€20 for volunteers. For species that cannot be identified in the field, e.g. for hoverflies and solitary bees, it is also possible to ask a volunteer to capture everything, which increases the identification costs. This will also decrease the availability of volunteers. The costs of this approach are estimated to be ~€79 per visit based on 4 visits per year (see section 5.5.1.2 for a complete cost overview).

Advantages

This method is relatively low-cost when volunteers are available to do the field work. It provides a passive way of collecting data, and hence it can be used to estimate abundance. The focus is on monitoring the main wild pollinators and there is increasing interest from the general public. For species groups that can be identified in the field directly annual monitoring results could become available with a minimal time-delay.

Disadvantages

In most countries there are difficult species pairs or groups that cannot be identified to species level in the field. The non-lethal and volunteer-friendly version of this method does not cover the more species-rich and important pollinator groups such as solitary bees and hoverflies, as their species-level identification is not possible in the field. For these groups lethal sampling will be required, which will most likely require paid field workers, and a longer processing time.

Examples

National monitoring schemes based on this method already exist in some European countries, but there are differences between the schemes in how exactly the monitoring is conducted. For example, Ireland has adopted very similar recording methodology to that used in butterfly monitoring for monitoring bumble bees, but based on 5 m wide transects. An Irish scheme[5] was started in 2011, and currently more than 100 transects are monitored annually. In Finland a similar scheme with 5 m wide transects was piloted with approximately 90 transects in summer 2019. The British 'Beewalk'[6] monitoring scheme was established in 2008, and is based on recording each bumble bee species seen in a 4 x 4 x 2 m recording box. It has currently more than 300 annual transect routes (Comont & Dickinson 2018). An Estonian bumble bee monitoring scheme was started in 2006, and focuses solely on agricultural areas; bumble bees are monitored in 66 farms based on 2 m wide and 500 m long transects placed mainly on field margins, and counted three times a year during June-August (Marja et

5 www.biodiversityireland.ie/record-biodiversity/bumblebee-monitoring-scheme
6 https://www.bumblebeeconservation.org/beewalk/

al., 2018; Eneli Viik, personal communication). In Sweden, bumble bees have been monitored along transects in meadows and pastures since 2006 within the National Inventory of Landscapes in Sweden (NILS)[7]. The length of these transects varies depending on the size of the meadow or pasture being surveyed, otherwise the method is the same as the 'Beewalk'. All these examples use a slightly different approach and methodology; for a good comparability a single protocol should be established. Additionally, although suitable weather conditions may differ between species, for clarity it may be necessary to establish a single set of weather requirements for all relevant pollinator groups (butterflies, bumble bees, hoverflies and solitary bees).

4.3.3 Point counts and timed counts

Description

In a standardised points count, butterflies are recorded within a radius of typically 25 m around and 5 m above an observer for 15 mins. The method can be used in open areas in all landscapes and surveys are repeated at least 3 to 7 times a season from spring to autumn. If a butterfly needs to be caught for determination (in the field or photographed) the timing and counting are temporarily stopped and continued afterwards. Counting is only undertaken in good weather when butterflies are active, i.e. not in cold, cloudy or windy weather. The habitat is also described, e.g. garden or meadow, with the most common plant species noted. This method is also sometimes called 'point inventory' or 'area-restricted timed counts'.

The reason for using this method within the Swedish Butterfly Monitoring scheme[8] (Figure 4.6), was to start to involve larger number of volunteers as this is a less demanding exercise than transect walks (personal comm., Lars Pettersson). It involves a different kind of counting than transect walks (section 4.3.1), but is similarly suitable for repeated and delimited inventories.

Figure 4.6. Picture from the Swedish Butterfly Monitoring Scheme description of methods[9]. Picture by Måns Sjöberg © Swedish Butterfly Monitoring Scheme.

Scope

Currently only butterflies and burnet moths (Zygaenidae) are counted as part of the Swedish Butterfly Monitoring scheme. However, it would potentially also be used also for bumble bees by choosing a smaller diameter of the circle to facilitate species level identifications.

Requirements

The only requirements are an insect net and literature for species determination. The field work can be conducted by volunteers. If the method is used to survey bumble bees, some additional training would be needed for volunteers to be able to undertake the inventory. It can be difficult to identify some bumble bees to species level in the field, and so they either need be caught for later species determination or grouped into similar species groups.

Costs

This method is relatively cheap, when based on volunteers. An insect net (~€33) and literature for identifications are all that is needed. This method is very straightforward and can be undertaken by most volunteers; this will likely increase the number of volunteers participating. Due to this broad interest it can no longer be assumed that volunteers will have their own net and

7 https://www.slu.se/en/Collaborative-Centres-and-Projects/nils/
8 https://www.dagfjarilar.lu.se/english
9 http://www.dagfjarilar.lu.se/hur-gor-man/metoder-0

reference literature at the outset. No specimens need to be identified in a lab, which makes this method relatively cheap compared to many others. Photographic documentation and subsequent consultation of experts for difficult species remains possible.

Advantages

The strength of the method is that it is very simple, especially using an app that has been developed for the Assessing butterflies in Europe project (ABLE, section 1.2.2), and probably increases the reporting frequency among volunteers (personal comm. Lars Pettersson). The method also works better in places such as gardens where it can be difficult to do transect walks. It is also easy to make repeated replicates and measurements, and to randomly select independent samples in an area. The method is not lethal unless specimens are caught for later species determination (e.g. if used for other species groups other than butterflies).

Disadvantages

Since the area monitored is rather small the method is sensitive to the availability of flower resources within the area at the time of inventory; for instance, a point in a garden might not include any flower resources at all until the middle of June (in Sweden) and therefore attract fewer pollinators (personal comm. Lars Pettersson). This can make the data hard to interpret. There might be some risk to double count individuals and this tendency likely varies between volunteers/field workers. As this method is very easy for volunteers to get involved in, the data quality might be hard to ensure. This could potentially be improved by offering (automatic) validation of pictures.

Examples

This method is used as a complement to transects in the Swedish Butterfly Monitoring Scheme[10]. Volunteers have used it to initiate their own local monitoring schemes, such as butterfly recolonisation of burnt areas within a Swedish mega fire (Gustafsson et al., 2019). The method will also be used as part of the Assessing butterflies in Europe project (ABLE)[11].

4.3.4 Flight interception traps

Description

The most commonly used flight interception trap is the Malaise trap (Malaise, 1937); this method of trapping includes a wide range of designs, some of which overlap with 'window traps'. The example illustration is just one of many types used (Figure 4.7). Flight interception traps are a passive lethal sampling technique designed to survey flying insects.

The most commonly used Malaise traps today are variants of the model by Townes (1972); this model offers two advantages, a lighter weight and a high output compared to some other Malaise traps (Matthews & Matthews, 1983). The effectiveness is primarily influenced by the trap model, the size of the entry area, the deployment time and trap orientation. These traps can be deployed for a short period or for a full season. Insects are generally killed by drowning them in ethanol. Comparison studies found that Malaise traps capture insects of many different groups, although they generally collect less material than attraction-based methods (Campbell & Hanula, 2007; Shweta & Rajmohana, 2018), therefore it has been suggested that Malaise traps should be combined with pan trapping (Darling & Packer, 1988). The lower number of captured insects, when compared to methods that actively attract insects, can however be used to provide occupancy data (Shweta & Rajmohana, 2018). When the design and use of Malaise traps is standardised for a scheme, and numerous traps are deployed for a sufficient length of time, a comparative assessment in space and time of pollinator trends is possible (e.g. Hallmann et al., 2017).

In the classic Malaise trap design, an insect flies into the trap, hits the net, flies up and is captured. A similar trap that is easier to deploy, is the window trap; here an insect flies into a piece of (transparent) plastic, falls down and is captured. Window traps are similar to Malaise traps, although the mesh size is known to be important in Malaise traps (Darling & Packer, 1988), hence a solid window will likely have a different trapping result. Additionally, window traps generally have a smaller trapping surface compared to Malaise traps (Peck & Davies, 1980). Hybrids between Malaise and window traps are also available, and these are named 'SLAM' traps and have an X-shaped window trap but are made of mesh.

Scope

Malaise traps are often used to collect insects for biodiversity surveys aiming to inventory the community of sites (e.g. Eymann et al., 2010; Karlsson et al., 2005). These traps capture a broad spectrum of flying insects; they have a relatively low capture

10 http://www.dagfjarilar.lu.se/english

11 https://butterfly-monitoring.net/bms-methods

Figure 4.7. Townes model Malaise trap on the left, window trap on the right. Note these are examples of many Malaise and window trap models in use. Pictures by Bas Oteman.

rate and hence are unlikely to damage populations (Ssymank et al., 2018). The quality of the data strongly depend upon the standardisation in sampling design and the way they are deployed.

Requirements

In addition to the Malaise trap itself, there is a need for poles for the trap construction, collecting bottles, and preserving liquid (usually ethanol). When the trap is deployed for a longer period of time, the collecting bottles are usually changed weekly or every two weeks; in these cases a preserving liquid with a low evaporation rate is used (such as propylene glycol). The operation of Malaise traps, including changing the bottles on a weekly basis and documentation of the habitats with photographs, does not require expert knowledge and can be implemented by volunteer networks, although volunteers might not be readily available for this type of work in many countries. Experts are needed for the selection of locations, installation of the traps and to identify captured insects.

Costs

This method is relatively expensive as both the trap and the data processing are costly. The trap itself costs about €250. Other materials are similar to pan trapping, hence ~5 sampling tubes and ~100 ml of ethanol would be required per visit, costing ~€5 in total per visit or ~€21/year. Additionally, all specimens caught would require sorting and identification. In total, costs are ~€105/visit and ~€421/site/year.

Advantages

Malaise trapping is an effective way to collect quantitative data on the abundance of flying insects. It is one of the few methods, together with sweep netting, that does not include the biases associated with methods that rely on attracting insects, or problems associated with relying on human observers. As the sampling itself does not require expert knowledge, it can be used in citizen science networks.

Disadvantages

Malaise trapping is a technique that requires experts for identification, which makes it expensive and time-consuming. The processing time largely depends upon experts, and data are not usually quickly available. Not all species are equally captured by Malaise traps, and captured moths (and other species) can be difficult to identify as ethanol affects their colour. Malaise traps are typically left in the field for a longer period than most other traps; the volume of insect material caught is therefore quite high, requiring a large sorting effort. These traps capture a wide range of flying insects, of which only a small proportion are actual pollinators. The effectiveness of a Malaise trap is highly dependent upon the prevailing wind direction, and hence the trap has to be placed in accordance with the local dominant wind direction; this means trap placement has to be supervised by an expert, or volunteers have to be given very careful instructions. Malaise traps designs vary hugely, and standardised designs and deployment protocols need to be developed more widely. Because this trap does not attract insects, the number of captured insects per unit time is relatively low, therefore more traps need to be placed, or traps need to be placed for longer periods , in order to capture sufficient specimens to track trends in species. In very open areas, wind damage can cause problems for Malaise traps.

Examples

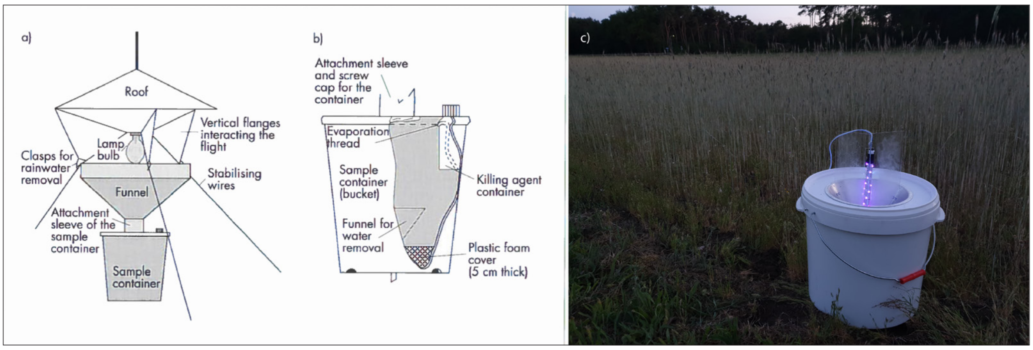
Malaise trapping is often used for surveying around the world, and data collected with this method has recently been used to document the decline of insect biomass in Germany over the last thirty years (Hallmann et al., 2017).

4.3.5 Light Traps

Description

A light trap uses light to attract night active insects (mostly moths), and by moving towards the light the insect gets trapped (Figure 4.8). Depending on the type of light source and the species, moths are attracted from 10 to 120 m away (Merckx & Slade, 2014). Moths have been studied like this for many years (Taylor & French, 1974) and several different types of trap have been developed. The strength of the light, trapping mechanism and size (and hence trapped insect storage capacity) can vary hugely (Leinonen et al., 1998). The wavelength largely determines which species are attracted, with wavelengths between 300-400nm (covering UV), generally attracting more species and larger species (Pöyry et al., 2011; van Langevelde et al., 2011).

Figure 4.8. To the left are two pictures (a+b) indicating the main parts of a light trap, pictures from *Söderman (1994).* The bucket type (c) is currently being used in the Netherlands to set up a large scale agricultural monitoring scheme[12] (Picture by Jurriën van Deijk).



Scope

This method is focussed solely on night-active insects that are attracted by light. Much remains unclear about this group of pollinators, although it is becoming increasingly clear that this group may make an important contribution to pollination (Walton et al., 2020), and has a non-redundant contribution when compared with diurnal pollinators (Knop et al., 2017). Not all moths are attracted by light, and it remains uncertain why some families are attracted by light while others are not (Merckx & Slade, 2014). Nevertheless, when light trapping is employed with sufficient frequency over several years, low powered traps in particular can give highly detailed information on population trends in moths in a particular location (Bell et al., 2020; Macgregor et al., 2019).

Requirements

Light traps can be deployed with ethyl-acetate, ethanol, formaldehyde or chloroform (more suitable for long-term deployment) to kill and preserve captured insects. Ethyl-acetate is preferred, as ethanol or formaldehyde make identification difficult (and formaldehyde is highly restricted in its use for health and safety reasons). These traps have to be checked weekly by a professional recorder, as finding enough volunteers willing to regularly collect dead insects is usually difficult (although this will likely differ between countries). Alternatively, light traps can be deployed in a non-lethal manner, which requires daily checks. Specimens have to be identified prior to release, and this can be supported by image recognition apps. These apps seem well able to identify species from pictures in western Europe, but are currently unlikely to perform so well in eastern Europe, as the number of species is larger and reference material to train the algorithms is less likely to be available. Therefore, especially in eastern Europe, additional experts need to be available to support identification efforts. Dead specimens are dissimilar in their pose to living specimens, and hence are likely to be difficult to identify using the existing recognition software. So either identification of dead specimens should be done by experts, or the recognition algorithm has to be restructured to work with dead specimens.

12 https://www.vlinderstichting.nl/bimag

Costs

For the cost estimate of this method we assume that volunteers place and empty the trap four times a year. When a killing agent is used, an expert has to analyse all collected specimens, which brings the cost to ~€325 per visit. When the traps are deployed without a killing agent they cost ~€75 per visit. However, it must be kept in mind that without poison the traps will be less effective, as they are deployed for a single night each time, and the lethal traps are deployed for a week at a time.

Advantages

Light traps provide the most effective way to monitor night active insects that have an important role in pollination. The traps are efficient, they are easy to deploy and the specimens are easily collected. There are an increasing number of volunteers involved in light trapping networks (using both lethal and non-lethal traps) in north-west Europe. If an identification app is used[13], as is currently the case in the Netherlands, even untrained volunteers can make their data quickly available for research.

Disadvantages

The biggest disadvantage is that this method only attracts night-active insects, and only the subset that is attracted to light. This subset is expected to represent night pollinators reasonably well (Merckx & Slade, 2014; Walton et al., 2020), but it remains completely unknown how this relates to pollinators in general. The performance of this method is known to depend upon landscape type, with highest capture rates in relatively closed landscapes (Merckx & Slade, 2014). This trap cannot be deployed near other light sources, and depending on the lamp type it should be deployed 50 to 150 m from the nearest light source. The non-lethal variety of this trap has the possibility of recapturing individuals, and while unpublished data suggests these effects are limited, we cannot conclude it will not be a problem.

Examples

A simple model that recently gained popularity in the Netherlands is an UV-LED light strip mounted on top of a bucket, with a funnel underneath and Plexiglas plates surrounding the light (Figure 4.8). This model runs on a battery, and the light automatically turns on at night. Traditional models use a stronger light, and therefore require an external power connection. In the Netherlands this trap is currently being used to set up a national moth monitoring scheme focussed on agricultural areas. In England, monitoring moths has been ongoing since 1967 in large-scale networks such as the Rothamsted Insect Survey (RIS)[14] and a large-scale volunteer trapping network[15] (see: Bell et al., 2020; Conrad et al., 2006). In Finland[16], a moth monitoring scheme based on 50 to 150 annually operating Jalas type of light traps has been running since 1993 (Pöyry et al. 2011, Leinonen et al. 2016). The fresh samples killed in the traps by chloroform/tetrachlorethane were frozen during the sampling season, from April to October, and the macro-moths identified by volunteers during winter time. The scheme has detected relatively large changes in moth species, abundances and phenology in Finland over the last 25 years.

4.4 Methods targeting resting insects

4.4.1 Sweep netting

Description

A sweep net can be used to sample the top 25 to 50% of the vegetation along a fixed transect (100 to 300 m). The number of sweeps is fixed (e.g. 50), and all captured insects are collected after each set of sweeps. Sweep-netting is often used because the equipment is lightweight, cheap and simple to use (Buffington & Redak, 1998; Doxon et al., 2011). A similar mechanised technique is available which uses a vacuum system to suck in insects (e.g. D-vac or Vortis); and is known to outperform the manual sweep net when collecting Diptera, Homoptera, and Hymenoptera (Doxon et al., 2011), but captures fewer large insects (Doxon et al., 2011), and has much higher operating costs (Ellington et al., 1984).

Sweep netting is often used as a reference to assess the effectiveness of other techniques (Klein et al., 2006; Monsevičius, 2004; Tscharntke et al., 1998); it has been compared with pan trapping where it was found to perform similarly (Monsevičius, 2004; Richards et al., 2011), and trap nesting (Klein et al., 2006; Tscharntke et al., 1998). Although Richards et al. (2011) noted that for bees, Halictidae

13 https://play.google.com/store/apps/details?id=org.observation.obsidentify&hl=en_US
14 https://www.rothamsted.ac.uk/insect-survey
15 https://butterfly-conservation.org/news-and-blog/journey-to-the-moth-atlas-producing-the-first-ever-atlas-of-larger-moths-in-britain
16 https://helda.helsinki.fi/handle/10138/161221

are better caught using pan traps, and it was more effective to collect Apidae using sweep netting. Nielsen et al (2011) showed that although pan traps captured more bee species at a local scale, sweep netting outperformed them when more study sites were included.

Scope

This method samples the top layer of the vegetation, and hence works well to capture leaf visiting insects. Weather conditions are an especially important factor when interpreting samples collected using this method (Hughes, 1955; Lowrie, 1971).

Requirements

Sample collection requires little training, but data processing usually requires an expert due to the wide variety of taxa collected and because insects are often damaged (and sometimes identification is not always possible for damaged individuals). Because the collecting is relatively time- consuming, and more labour intensive than a simple transect walk, finding sufficient volunteers can be difficult.

Costs

For the cost estimate, we assume volunteers collect the samples, and data are processed by experts, which makes this method moderately expensive. The material (sweep net, sampling pots and ethanol) are relatively cheap, but the identification of some, or all, specimens has to be done by experts. The costs of this method are estimated to be ~€79 for data collection, and ~€84 for identification per visit. In total, this method will cost ~€652, based on 4 visits per year.

Advantages

Sweep netting is relatively easy for a volunteer to do and very little training is required. This method provides information on many groups of insects, and does not depend upon flight or attraction of insects. Therefore, it is more likely than some other methods to represent the pollinator community.

Disadvantages

This method has a bias towards leaf and flower visiting insects, and hence is strongly affected by weather conditions affecting insect activity. An expert has to sort through the collected samples, which can be damaged by the collecting process. This technique cannot be used in all landscape types; sampling in forest understories or thorny shrub vegetation is impracticable (Campbell & Hanula, 2007), due to the inability to operate a sweep net in these habitats. Even in suitable landscape types the results can depend on the vegetation structure. As with many of the other methods there is a potentially large effect of flower richness, therefore transects should be chosen that well represent the landscape.

Examples

No large-scale monitoring schemes using this method are currently running and so its effectiveness for monitoring pollinators as a whole is unknown. Monitoring focused on individual, mostly pest, species has been undertaken with this method (Nielsen et al., 2011; Zink & Rosenheim, 2004).

4.5 Methods targeting breeding or overwintering insects

4.5.1 Pheromone traps for moths

Description

Female moths use pheromones to attract males; pheromone traps contain chemically synthesised pheromones to attract and trap male moths (Figure 4.9). This technique originated as a means of pest control and was found to be only moderately effective (Garrevoet, 1997). The commercially available pheromones generally only attract a single species, and the attraction distance of pheromones is largely unknown and differs between species, but estimates of up to 500 m have been published (Schlyter, 1992).

Scope

This method can only be used to attract male moths of a single species during the season they are sexually active. Several moth groups such as the clearwing moths (Sesiidae), which are not attracted to light, are best studied using pheromones (Burman et al., 2016), however the effectiveness of pheromones is unknown for most moth species. A recent study found that the physical design of the trap,

Figure 4.9. Left is the whole pheromone trap, on the right is a close-up of the pheromone lure. Pictures by Bas Oteman.

and not just the pheromone being used, has a strong influence on the trapping effectiveness for a specific species (Madsen & Vakenti, 2019). So this method is really only suitable for collecting detailed information on a single species for which the pheromone is available.

Requirements

This method requires little training and is extremely easy to deploy. A pheromone trap requires a single lure per year. The trap is most effective when the species is sexually active. Once the trap is deployed it is checked daily to weekly, depending on whether captured individuals are killed or released. Killing is not required for identification as only one species is attracted.

Costs

This method is relatively cheap as it requires only a trap and a pheromone lure which can be used for a year. A single trap costs about ~€3 per visit per species based on 4 visits per year. In total, assuming 5 traps are used, this method costs ~€60 per site per year (for a single species).

Advantages

Pheromone raps are the preferred method of study for several moth species. Placement and collection are extremely simple and little training is required.

Disadvantages

Data are only for a single species and it is often unclear if a species will respond well to pheromone trapping. Pheromone trapping only catches males which has to be taken into account when interpreting these data, especially when studying a species that has a difference in mobility between the sexes. Even though pheromone traps can attract moths from relatively long distances, the effectiveness of traps was found to be highly dependent on its direct surroundings (Riedl & Croft, 1974).

Examples

This method is not used in a long-term monitoring scheme, but is being used in studies focusing on a single species. In Sweden a study showed that a sampling bias for the species *Synanthedon vespiformis* decreased when this method was used compared to others. It has been used in other regions in north-western Europe for the same group of moths as well (Garrevoet 1997).

4.5.2 Trap nests

Description

Trap nests of various kinds have been used to study solitary bees for about a century (MacIvor, 2017). Trap nests are sheltered bundles of hollow plant stems, such as reeds (mostly *Phragmites australis*) or bamboo; they can also be made by drilling holes into wooden blocks or making cavities in other materials (Figure 4.10). Cavity length and width varies between studies, but all aim to represent the typical physical dimensions of nests used by trap nesting bees in the wild. A length of at least 150 mm is often recommended; over-short nest cavities may result in an increased production of male offspring since the brood cells close to the opening often result in male individuals. The width of the cavities determine which species can use them, and it can also alter the sex ratio of the offspring. Nesting cavity diameters (width) reported from different studies vary from 2 to 3 mm up to 25 mm.

Figure 4.10. Trap-nests with reed internodes. Picture by Riccardo Bommarco.

Scope

Trap nests sample cavity nesting species of solitary bees and wasps. The trap nests can be placed in different environments to monitor local bee and wasp diversity (O'Neill and O'Neill, 2010). Information on parasitism and pollen collected in nest cells can also be obtained using this method (Tscharntke et al., 1998; Williams, 2003). In Tscharntke et al. (1998) the species richness of bees and wasps inhabiting the trap-nests mirrored the species richness of bees and wasps caught with sweep nets in the same area. However, a comparison of methods (Westphal et al., 2008) found that species richness of trap-nests only weakly indicated the overall bee species richness of a site.

Requirements

Building material to create trap nests such as reed or bamboo sticks is needed, as well as plastic tubes of 130 to 150 mm diameter and 150 to 200 mm length to put the sticks in, poles to attach them to, and mesh to cover the entrance to avoid predation from birds. Similar trap-nests with paper tubes can also be obtained commercially[17]. However, such paper tubes have a limited number of diameters and may not perform as well as the reed internodes (Westphal et al., 2008).

Trap nests intended to sample bee and wasp diversity should provide cavities with different diameters since species tend to choose cavities matching their own body width. Small cellophane bees (e.g. *Hylaeus* spp.) use nests of 1 to 4 mm diameters whereas medium-sized bees (e.g. *Megachile* spp. and *Osmia* spp.) use 5 to 8 mm diameter tubes (MacIvor, 2017). Reed internodes have diameters that are typically in the intervals 2 to 10 mm (Westphal et al. 2008).The recommended placement of a trap nest is with the entrance facing east or south (so the entrance gets morning sun) and above the local basal vegetation height (MacIvor, 2017). Trap nests are normally placed on a pole or a tree at a height of about 1.5 m. Trap nests that are left unattended in the field may need a net or mesh covering over the entrance to avoid predation from birds. Trap nests can be set out in the spring (around April in most of Europe) and collected in the late autumn (around October) the same year or even left out for several seasons. To sample diversity in different habitats or along an environmental gradient, it is recommended that trap nests are placed over as wide an area as possible (MacIvor, 2017). At the end of the season, the occupied tubes need to be collected, stored over winter and insects then reared after diapause/hibernation (after around three months at low temperature) (Westphal et al., 2008).

Volunteers could be involved in placing, monitoring and gathering the trap nests, and perhaps also in building them. Species experts are needed to go through the collected nests and either determine the larvae to species, or rear the larvae to adults for species determination. Since the number of species occupying these nests is limited, it may be possible for non-specialists to do the species determination, with suitable training.

17 https://www.masonbees.co.uk/shop


Collecting pollinators by sweep net, Tamara Tot

Costs

Trap nests are relatively cheap to purchase or build, for example one commercial nest using plastic tubes with 42 paper tubes (of 8 mm diameter) would cost between ~€11 to 15. Building the nests with reeds is much cheaper if reeds can be (sustainably and legally) harvested locally. Additional costs would include the stations for the trap nests (assumed to be approximately the same as for pan traps) and mallets to install them. In total, a set of 3 trap nests per site, including stations, would cost ~€79/site. The largest costs using this method are costs for distributing, setting up and collecting in the nests (if this is not done by volunteers), rent for a location to store and rear the insects, as well as species experts to sort and determine the insects to species. The total scale of these costs will in turn depend upon the size of the network proposed.

Advantages

This method captures information on the environment where the bees and wasps live (not just passing through), and information on other aspects of the bee community that other methods cannot, such as parasitism and reproduction. It is also possible to get information on the type of pollen and prey used to feed the larvae, and the building materials used by the bee and wasp species. Thus, trap nests can be used to gain information on multi-trophic interactions and the needs of the bees and wasps studied. As trap nests are set out in the spring and collected in autumn, the effort of using this method will be very low during the field season. This makes it possible to use it in combination with other more fieldwork-intense methods.

Disadvantages

The method only catches a small fraction of solitary bees and wasps that are able to utilise man-made trap nests as nesting sites. According to Tscharntke et al. (1998, citing Krombein 1967) this includes about 5% of all bee and wasp species. Since they do not capture so many species, the possibility to detect differences between habitats using trap nests is limited (Westphal et al., 2008). Since the traps need to be out in the field during the whole season, there is a risk that they can be damaged or destroyed by people, animals or severe weather conditions. The handling of collected nests, including the storage of occupied tubes and rearing of insects, is both time and space demanding.

There is a possibility of competition with existing potential nest locations; if many potential nesting locations are available, the usage of the trap nests will likely decrease. If few are available, the local population might increase due to colonisation. This complicates data interpretation.

Collecting pollinators by sweep net, Tamara Tot

Examples

An example of a large-scale study (i.e. over different countries) where trap nests have been used to sample diversity, is the single year study of Westphal et al. (2008) which compared the efficiency of different bee sampling methods. However, trap nests have been used in numerous studies with different purposes, such as looking at multi-trophic interactions (Ebeling et al., 2012; Tylianakis et al., 2006), pollen use (Williams, 2003), foraging range (Gathmann & Tscharntke, 2002), and effects of landscape change (Diekötter et al., 2014; Klein et al., 2006).

4.5.3 Egg and larval counts

Description

For some butterflies, counting eggs is more effective than counting adults. Professionals or trained volunteers can recognise eggs of a particular species by examining the known host plants and counting the number of eggs. This monitoring method can be extended by collecting some eggs for genetic analysis. For some species, larval colonies can be surveyed in a similar way, such as M*elitaea cinxia, Euphydryas aurinia* and *E. maturna*.

Scope

This method has thus far only been deployed for butterflies, as detailed knowledge about their expected habitat is required to limit the search, but with further development it might be used for some moth species as well. This method is only recommended for a few species that cannot easily be monitored using other techniques, and whose eggs or larvae are morphologically distinct or have obligatory host plants.

Requirements

This method requires little training, and has no other specialist requirements. Its simplicity makes it well-suited for volunteers.

Costs

The method is cheap, if skilled volunteers are available for counting butterfly eggs. Material costs are limited to a hand lens, providing one to volunteers if needed. Costs are estimated at ~€3 per visit with 4 visits a year, if a hand lens is provided, otherwise there are no costs.


Collecting pollinators by sweep net

Advantages

Volunteers can easily collect the data, and some species are hard to monitor in another way. Depending on the species, data can also be collected in winter.

Disadvantages

Data are only of a single species, and the habitat of this target species has to be well defined. Several moth species could also be monitored effectively with this method, if their habitat uses are sufficiently well described. Although this method is relatively cheap, it is also very time-consuming, and overall an ineffective way of collecting data on pollinators as a whole. By definition, the species best monitored by counting eggs differ from most pollinators (they are not easily seen or captured using the previously described methods) and hence these species cannot be expected to represent trends in pollinators. The data quality strongly depends on the detectability of the egg or larvae; a high number of potential host plants can decrease detections chances, which can complicate data interpretation.

Examples

Butterfly Conservation Europe (BCE) recognises that for species such as *Phengaris alcon* or *Thecla betulae* counting eggs is the most effective monitoring method (van Swaay et al 2012). This method is currently employed in several north-eastern European countries. Similarly, in Sweden, two of the species within the EU Habitats Directive (*Euphydryas aurina* and *E. maturna)* are monitored through counting larval colonies. *Melitaea cinxia* is another butterfly species with long-term monitoring schemes based on counting its larval groups (Curtis et al., 2015; Ojanen et al., 2013).

4.6 Rationale for methods proposed for the EU Pollinator Monitoring Scheme

4.6.1 Critical assessment of methods

The consensus of the expert group was that the Core Scheme (see Figure 0.1) should focus upon bees (bumble bees and solitary bees), hoverflies, butterflies, moths, and include rare and threatened pollinator species; with pollination services, flower visitors and wider flying insect biodiversity as additional add-ons (section 5.4). For a pan-European monitoring scheme, data on these taxa must not only include occupancy and diversity, but also an abundance measure. There is no ideal sampling method for

Collecting pollinators by sweep net, Tamara Tot

these taxa, as all methods have biases and limitations. Therefore, experts critically evaluated the range of available standardised methods for sampling pollinators as part of an EU pollinator monitoring scheme in terms of: quality of data produced; biases and limitations; feasibility and appeal for citizen scientists; requirements for sample processing, identification and longer term storage; costs (time, effort and equipment); and, for lethal methods, the likely impact on local populations. Based on this assessment, a set of recommended method(s) were proposed to be included in the Core scheme (section 5.2), with additional methods to be considered as optional Complementary Approaches (section 5.3) to the Core scheme.

4.6.2 Recommendation of methods to be used in the pollinator monitoring scheme

Use a combination of a passive method (that does not rely on attracting insects) and an active method (that does rely on attracting insects); use the passive method to establish general trends of pollinator groups, and the active method to establish occupancy at a species level. Specifically, it is recommended to combine standardised *transect walks* (passive, sections 4.3.1 and 4.3.2) by volunteers focused on bees, butterflies and hoverflies with *pan trapping* (active, section 4.2.4) to collect a wider range of taxa using a combination of volunteers or paid staff/technicians to set and collect traps, with identification of captured insects undertaken by experts.

As there is ongoing research into the representativeness of pan traps, their data cannot be used to estimate absolute abundance (section 4.3.2). It is therefore suggested that in countries with a strong history of *Malaise trapping* (where the required material and expertise are available, sections 4.3.4 and 5.3.4) the two trap types are deployed in parallel so their effectiveness can be compared.

As an optional add-on to the regular measurements it is also recommended that the use of *light traps* (section 4.3.5) could be used to monitor moths (section 5.3.3). Emerging studies indicate that moths may be important pollinators of some wild flowers; however their role in pollination of these species is poorly understood. Therefore, moths are not included in the Core scheme, but can be an important complement to methods suited to day-flying insects.

4.6.3 Rationale for methods choice

It is proposed that the Core scheme focuses on methods that capture many species (from as many different pollinator groups as possible), rather than selecting a single group and assume it represents all pollinators. This excludes targeted searches (for

Osmia rutila, Nicolas J. Vereecken

individuals or eggs), and pheromone traps, as those are always focused on a single species. These methods might be deployed to collect additional information to better monitor specific rare species (see section 5.3.2).

The methods known to capture large numbers of insects generally rely on attraction by colour. This is favourable as it attracts flower visiting insects, which are most likely to be pollinators, but it also creates a bias. The trap competes with flowers for attention, therefore the number of captured insects can depend on the flower richness of the local environments. Some of these effects can be mitigated by collecting additional data (such as floral community composition), but will require further development and testing. These attraction-based methods are ideally suited to measure occupancy (which species are present), but measuring abundance (how many individuals are there) is much more difficult (see section 6.1.2).

Passive methods (methods that do not rely on attracting insects) have a much lower chance of capturing an insect than active methods, and will have to be deployed for longer or more often to obtain similar results. However, they can provide both occupancy and abundance data because their observation/trapping chances are less affected by surroundings. Flower availability has a strong effect on insects, therefore it is important for all methods that transects and plots are located in a way that represents the local surroundings well.

The available active methods are sugar bait traps (section 4.2.2), pheromone traps (section 4.5.1), light traps (section 4.3.5), Russell's yellow traps (section 4.2.3) and pan traps (section 4.2.4). Sugar baits and pheromones only attract a limited number of species, and are therefore not fit to establish occupancy for many species. Light traps are a highly effective way of monitoring night-active insects, such as moths, but cannot be used to monitor species that are not attracted by light. Russell traps are potentially very destructive for bee populations, and a large monitoring scheme based on these traps could have a detrimental effect on pollinator populations. The effectiveness of pan traps is highly debated but when deployed in a large enough quantity they generally provide reliable occupancy data, and they have limited effect on pollinator populations. Therefore pan trapping is the most suitable active method to measure a large number of pollinator groups without a large detrimental effect on pollinator populations.

Using passive methods, it is possible to collect sufficient data to obtain a general trend with a relatively low measurement intensity, to provide detailed occupancy data (see all species at least once) for all pollinator species or even a trend per species would require a large sampling effort (section 5.1).

To collect reliable abundance data we recommend a passive method. This likely involves a large (and potentially expensive) sampling effort; we therefore recommend using methods that appeal to volunteers. Available passive methods are: trap nests (section 4.5.2), egg counts (section 4.5.3), flower visitor counts (section 4.2.1), point inventory (section 4.3.3), transect walks (sections 4.3.1 and 4.3.2), flight interception traps (section 4.3.4) and sweep nets (section 4.4.1). Trap nests and egg counts are focused on a single species, or a small group of species. These techniques can be used to monitor specific rare pollinators but cannot be used to monitor large groups. Flower visit counts, point inventories and sweep nets are susceptible to observer effects; and so will require strict protocols for standardisation or statistical methods to account for bias.

Transect walks counting butterflies or other pollinators theoretically suffer from the same problems, but already have well-established protocols to deal with this, and statistical corrections for observer effects are possible as a volunteer is asked to repeatedly count the same transect. Additionally, as transect counts are non-lethal, it will be generally easier to find volunteers than for methods that depend on capturing and killing specimens (e.g. sweep nets or Malaise trapping). A butterfly monitoring system based on transect counts is already in place or under construction in many countries. We therefore recommend a repeated transect walk counting focussed on collecting species level data for butterflies, bumble bees, solitary bees and hoverflies. Volunteers should strongly be encouraged to report to species level (this should be supported by an (automated) validation process), but at least the number of individuals within those groups should be reported. It is likely that especially solitary bees and hoverflies cannot be identified on a transect, and we recommend capturing everything for these groups. This will make this method less appealing to volunteers. A single protocol needs to be tested and selected before this method is widely implemented (Chapter 9).

References

Baum KA, & Wallen KE (2011). Potential bias in pan trapping as a function of floral abundance. *Journal of the Kansas Entomological Society*, *84*(2), 155–160.

Bell JR, Blumgart D, & Shortall CR (2020). Are insects declining and at what rate? An analysis of standardised, systematic catches of aphid and moth abundances across Great Britain. *Insect Conservation and Diversity*, *13*(2), 115–126.

Buffington ML, & Redak RA (1998). A comparison of vacuum sampling versus sweep-netting for arthropod biodiversity measurements in California coastal sage scrub. *Journal of Insect Conservation*, *2*(2), 99–106.

Burman J, Westerberg L, Ostrow S, Ryrholm N, Bergman K.-O, Winde I, … Milberg P (2016). Revealing hidden species distribution with pheromones: the case of Synanthedonvespiformis (Lepidoptera: Sesiidae) in Sweden. *Journal of Insect Conservation*, *20*(1), 11–21.

Campbell JW, & Hanula JL (2007). Efficiency of Malaise traps and colored pan traps for collecting flower visiting insects from three forested ecosystems. *Journal of Insect Conservation*, *11*(4), 399–408.

Cane JH, Minckley RL, & Kervin LJ (2000). Sampling bees (Hymenoptera: Apiformes) for pollinator community studies: pitfalls of pan-trapping. *Journal of the Kansas Entomological Society*, 225–231.

Carvell C, Isaac NJB, Jitlal M, Peyton J, Powney GD, Roy DB, … Roy HE (2016). Design and Testing of a National Pollinator and Pollination Monitoring Framework. *Final Summary Report to the Department for Environment, Food and Rural Affairs (Defra), Scottish Government and Welsh Government: Project WC1101.*, (April). Retrieved from http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=2&ProjectID=19259

Conrad KF, Warren MS, Fox R, Parsons MS, & Woiwod IP (2006). Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. *Biological Conservation*, *132*(3), 279–291.

Curtis RJ, Botham MS, Brereton TM, & Isaac NJB (2015). The rise and demise of the Glanville fritillary on the Isle of Wight. *Journal of Insect Conservation*, *19*(2), 305–311.

Darling DC, & Packer L (1988). Effectiveness of Malaise traps in collecting Hymenoptera: the influence of trap design, mesh size, and location. *The Canadian Entomologist*, *120*(8–9), 787–796.

Dauber J, Hirsch M, Simmering D, Waldhardt R, Otte A, & Wolters V (2003). Landscape structure as an indicator of biodiversity: matrix effects on species richness. *Agriculture, Ecosystems & Environment*, *98*(1–3), 321–329.

Dennis EB, Freeman SN, Brereton T, & Roy DB (2013). Indexing butterfly abundance whilst accounting for missing counts and variability in seasonal pattern. *Methods in Ecology and Evolution*, *4*(7), 637–645.

Devictor V, Van Swaay C, Brereton T, Brotons L, Chamberlain D, Heliölä J,   Lindström Å (2012). Differences in the climatic debts of birds and butterflies at a continental scale. *Nature Climate Change*, *2*(2), 121.

Diekötter T, Peter F, Jauker B, Wolters V, & Jauker F (2014). Mass-flowering crops increase richness of cavity-nesting bees and wasps in modern agro-ecosystems. *Gcb Bioenergy*, *6*(3), 219–226.

Doxon ED, Davis CA, & Fuhlendorf SD (2011). Comparison of two methods for sampling invertebrates: vacuum and sweep-net sampling. *Journal of Field Ornithology*, *82*(1), 60–67.

Droege S, Tepedino VJ, LeBuhn G, Link W, Minckley RL, Chen Q, & Conrad C (2010). Spatial patterns of bee captures in North American bowl trapping surveys. *Insect Conservation and Diversity*, *3*(1), 15–23.

Ebeling A, Klein A-M, Weisser WW, & Tscharntke T. (2012). Multitrophic effects of experimental changes in plant diversity on cavity-nesting bees, wasps, and their parasitoids. *Oecologia*, *169*(2), 453–465.

Ekroos J, Rundlöf M, & Smith HG (2013). Trait-dependent responses of flower-visiting insects to distance to semi-natural grasslands and landscape heterogeneity. *Landscape Ecology*, *28*(7), 1283–1292.

Ellington J, Kiser K, Ferguson G, & Cardenas M (1984). A comparison of sweepnet, absolute, and insectavac sampling methods in cotton ecosystems. *Journal of Economic Entomology*, *77*(3), 599–605.

Eymann J, Degreef J, Häuser C, Monje JC, Samyn Y, & VandenSpiegel D (2010). *Manual on field recording techniques and protocols for All Taxa Biodiversity Inventories and Monitoring*. Abc Taxa.

Garratt MPD, Potts SG, Banks G, Hawes C, Breeze TD, O'Connor RS, & Carvell C (2019). Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services. *Global Ecology and Conservation*, *20*, e00781.

Garrevoet T (1997). Het inventariseren van wespvlinders (Sesiidae) met behulp van feromonen. *De Levende Natuur*, *98*(5), 180–183.

Gathmann A, & Tscharntke T (2002). Foraging ranges of solitary bees. *Journal of Animal Ecology*, *71*(5), 757–764.

Gezon ZJ, Wyman ES, Ascher JS, Inouye DW, & Irwin RE (2015). The effect of repeated, lethal sampling on wild bee abundance and diversity. *Methods in Ecology and Evolution*, *6*(9), 1044–1054.

Gustafsson L, Berglind M, Granström A, Grelle A, Isacsson G, Kjellander P, … Strengbom J (2019). Rapid ecological response and intensified knowledge accumulation following a north European mega-fire. *Scandinavian Journal of Forest Research*, *34*(4), 234–253.

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H,   Hörren T (2017). *More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS ONE12 (10): e0185809*.

Hughes RD (1955). The influence of the prevailing weather on the numbers of Meromyza variegata Meigen (Diptera, Chloropidae) caught with a sweepnet. *The Journal of Animal Ecology*, 324–335.

Isaac NJB, Cruickshanks KL, Weddle AM, Marcus Rowcliffe J, Brereton TM, Dennis RLH, … Thomas CD (2011). Distance sampling and the challenge of monitoring butterfly populations. *Methods in Ecology and Evolution*, *2*(6), 585–594.

Itämies JH, Leinonen R, & Meyer-Rochow VB (2011). Climate Change and Shifts in the Distribution of Moth Species in Finland, with a Focus on the Province of Kainuu. *Climate Change–Geophysical Foundations and Ecological Effects. Rijeka*, 273–296.

Karlsson D, Pape T, Johansson KA, Liljeblad J, & Ronquist F (2005). Svenska Malaisefälleprojektet, eller hur många arter steklar, flugor och myggor finns i Sverige? *Entomologisk Tidskrift*, *126*(1–2), 43–53.

Kery M, & Plattner M (2007). Species richness estimation and determinants of species detectability in butterfly monitoring programmes. *Ecological Entomology*, *32*(1), 53–61.

Kirk WDJ (1984). Ecologically selective coloured traps. *Ecological Entomology*, *9*(1), 35–41.

Klein A.-M, Steffan-Dewenter I, & Tscharntke T (2006). Rain forest promotes trophic interactions and diversity of trap-nesting Hymenoptera in adjacent agroforestry. *Journal of Animal Ecology*, *75*(2), 315–323.

Knop E, Zoller L, Ryser R, Gerpe C, Hörler M, & Fontaine C (2017). Artificial light at night as a new threat to pollination. *Nature*, *548*(7666), 206.

Kuussaari M, Heliölä J, Tiainen J, & Helenius J (2008). Significance of the Finnish Agri-Environment Support Scheme for Biodiversity and Landscape: Final Report 2000–2006. *Suomen Ympäristö*, *4*(2008), 1–208.

Laaksonen J, Laaksonen T, Itamies J, Rytkonen S, & Valimaki P (2006). A new efficient bait-trap model for Lepidoptera surveys-the" Oulu" model. *Entomologica Fennica*, *17*(2), 153.

LeBuhn G, Droege S, Connor E, Gemmill-Herren B, & Azzu N (2016). Protocol to Detect and Monitor Pollinator Communities: Guidance for Practitioners. *Food and Agriculture Organization (FAO): Rome, Italy*.

Leinonen R, Söderman G, Itämies J, Rytkönen S, & Rutanen I (1998). Intercalibration of different light-traps and bulbs used in moth monitoring in northern Europe. *Entomologica Fennica*, *9*(1), 37–51.

Lowrie DC (1971). Effects of time of day and weather on spider catches with a sweep net. *Ecology*, *52*(2), 348–351.

Macgregor CJ, Williams JH, Bell JR, & Thomas CD (2019). Moth biomass increases and decreases over 50 years in Britain. *Nature Ecology & Evolution*, *3*(12), 1645–1649.

MacIvor JS (2017). Cavity-nest boxes for solitary bees: a century of design and research. *Apidologie*, *48*(3), 311–327.

Madsen H, & Vakenti JM (2019). The influence of trap design on the response of codling moth (Lepidoptera: Olethreutidae) and fruittree leafroller (Lepidoptera: Tortricidae) to synthetic sex attractants. *Journal of the Entomological Society of British Columbia*, *70*, 5–8.

Malaise R (1937). A new insect-trap. *Entomologisk Tidskrift*, *58*, 148–160.

Marja R, Viik E, Mänd M, Phillips J, Klein A, & Batáry P (2018). Crop rotation and agri-environment schemes determine bumblebee communities via flower resources. *Journal of Applied Ecology*, *55*(4), 1714–1724.

Matechou E, Freeman SN, & Comont R (2018). Caste-specific demography and phenology in bumblebees: modelling BeeWalk data. *Journal of Agricultural, Biological and Environmental Statistics*, *23*(4), 427–445.

Matthews RW, & Matthews JR (1983). Malaise traps: The Townes model catches more insects. *Contributions of the American Entomological Institute*.

Merckx T, & Slade EM (2014). Macro-moth families differ in their attraction to light: implications for light-trap monitoring programmes. *Insect Conservation and Diversity*, *7*(5), 453–461.

Mönkkönen M, & Mutanen M (2003). Occurrence of moths in boreal forest corridors. *Conservation Biology*, *17*(2), 468–475.

Monsevičius V (2004). Comparison of three methods of sampling wild bees (Hymenoptera, Apoidea) in Čepkeliai Nature Reserve (South Lithuania). *Ekologija*, *4*, 32–39.

Nielsen AL, Hamilton GC, & Shearer PW (2011). Seasonal phenology and monitoring of the non-native Halyomorpha halys (Hemiptera: Pentatomidae) in soybean. *Environmental Entomology*, *40*(2), 231–238.

Nielsen A, Steffan-Dewenter I, Westphal C, Messinger O, Potts SG, Roberts SPM, … Vaitis M (2011). Assessing bee species richness in two Mediterranean communities: importance of habitat type and sampling techniques. *Ecological Research*, *26*(5), 969–983.

O'Neill KM, & O'Neill JF (2010). Cavity-nesting wasps and bees of central New York state: the Montezuma wetlands complex. *Northeastern Naturalist*, *17*(3), 455–472.

Ojanen SP, Nieminen M, Meyke E, Pöyry J, & Hanski I (2013). Long-term metapopulation study of the Glanville fritillary butterfly (Melitaea cinxia): survey methods, data management, and long-term population trends. *Ecology and Evolution*, *3*(11), 3713–3737.

Paukkunen J, Heliölä J, & Söderman G (2008). Diversity of bees in agricultural landscapes. Significance of the Finnish Agri-Environment Support Scheme for Biodiversity and Landscape: Final Report 2000–2006. *Suomen Ympäristö*, *4/2008*(4/2008), 70–91.

Peck SB, & Davies AE (1980). Collecting small beetles with large-area" window" traps. *The Coleopterists' Bulletin*, 237–239.

Pettersson LB, & Franzén M (2008). Comparing wine-based and beer-based baits for moth trapping: a field experiment. *Entomologisk Tidskrift*, *129*(3), 129–134.

Pollard E (1977). A method for assessing changes in the abundance of butterflies. *Biological Conservation*, *12*(2), 115–134.

Pollard Ernest, & Yates TJ (1994). *Monitoring butterflies for ecology and conservation: the British butterfly monitoring scheme*. Springer Science & Business Media.

Pöyry J, Leinonen R, Söderman G, Nieminen M, Heikkinen RK, & Carter TR (2011). Climate-induced increase of moth multivoltinism in boreal regions. *Global Ecology and Biogeography*, *20*(2), 289–298.

Richards MH, Rutgers-Kelly A, Gibbs J, Vickruck JL, Rehan SM, & Sheffield CS (2011). Bee diversity in naturalizing patches of Carolinian grasslands in southern Ontario, Canada. *The Canadian Entomologist*, *143*(3), 279–299.

Riedl H, & Croft BA (1974). A STUDY OF PHEROMONE TRAP CATCHES IN RELATION TO CODLING MOTH (LEPIDOPTERA: OLETHREUTIDAE) DAMAGE 1 2. *The Canadian Entomologist*, *106*(5), 525–537.

Roulston TH, Smith SA, & Brewster AL (2007). A comparison of pan trap and intensive net sampling techniques for documenting a bee (Hymenoptera: Apiformes) fauna. *Journal of the Kansas Entomological Society*, *80*(2), 179–181.

Roy HE, Baxter E, Saunders A, & Pocock MJO (2016). Focal plant observations as a standardised method for pollinator monitoring: Opportunities and limitations for mass participation citizen science. *PloS One*, *11*(3), e0150794.

Schlyter F (1992). Sampling range, attraction range, and effective attraction radius: Estimates of trap efficiency and communication distance in coleopteran pheromone and host attractant systems 1. *Journal of Applied Entomology*, *114*(1-5), 439–454.

Schmucki R, Pe'Er G, Roy DB, Stefanescu C, Van Swaay CAM, Oliver TH, … Settele J (2016). A regionally informed abundance index for supporting integrative analyses across butterfly monitoring schemes. *Journal of Applied Ecology*, *53*(2), 501–510.

Shweta M, & Rajmohana K (2018). A comparison of sweep net, yellow pan trap and malaise trap for sampling parasitic Hymenoptera in a backyard habitat in Kerala. *Entomon*, *43*(1), 33–44.

Söderman G (1994). *Moth monitoring scheme. A handbook for field work and data reporting*.

Söderman G (1999). *Diversity of pollinator communities in Eastern Fennoscandia and Eastern Baltics. Results from pilot monitoring with Yellow traps in 1997-1998*. Finnish Environment Institute.

Söderman G, Leinonen R, & Lundsten K.-E (1997). *Monitoring bumblebees and other pollinator insects*.

Ssymank A, Sorg M, Doczkal D, Rulik B, Merkel-Wallner G, & Vischer-Leopold M (2018). *Praktische Hinweise und Empfehlungen zur Anwendung von Malaisefallen für Insekten in der Biodiversitätserfassung und im Monitoring.* Entomologischer Verein Krefeld.

Taylor LR, & French RA (1974). Effects of light-trap design and illumination on samples of moths in an English woodland. *Bulletin of Entomological Research*, *63*(4), 583–594.

Toler TR, Evans EW, & Tepedino VJ (2005). Pan-trapping for bees (Hymenoptera: Apiformes) in Utah's West Desert: the importance of color diversity. *Pan Pacific Entomologist*, *81*(3–4), 103–113.

Townes H (1972). A light-weight Malaise trap. *Entomological News*, *83*(9), 239–247.

Tscharntke T, Gathmann A, & Steffan-Dewenter I (1998). Bioindication using trap-nesting bees and wasps and their natural enemies: community structure and interactions. *Journal of Applied Ecology*, *35*(5), 708–719.

Tylianakis JM, Tscharntke T, & Klein A.-M (2006). Diversity, ecosystem function, and stability of parasitoid–host interactions across a tropical habitat gradient. *Ecology*, *87*(12), 3047–3057.

van Langevelde F, Ettema JA, Donners M, WallisDeVries MF, & Groenendijk D (2011). Effect of spectral composition of artificial light on the attraction of moths. *Biological Conservation*, *144*(9), 2274–2281.

van Swaay CAM, Nowicki P, Settele J, & van Strien AJ (2008). Butterfly monitoring in Europe: methods, applications and perspectives. *Biodiversity and Conservation*, *17*(14), 3455–3469.

Várkonyi G, Kuussaari M, & Lappalainen H (2003). Use of forest corridors by boreal Xestia moths. *Oecologia*, *137*(3), 466–474.

Walton RE, Sayer CD, Bennion H, & Axmacher JC (2020). Nocturnal pollinators strongly contribute to pollen transport of wild flowers in an agricultural landscape. *Biology Letters*, *16*(5), 20190877.

Westphal C, Bommarco R, Carré G, Lamborn E, Morison N, Petanidou T, ... Tscheulin T (2008). Measuring bee diversity in different European habitats and biogeographical regions. *Ecological Monographs*, *78*(4), 653–671.

Williams NM (2003). Use of novel pollen species by specialist and generalist solitary bees (Hymenoptera: Megachilidae). *Oecologia*, *134*(2), 228–237.

Wilson JS, Griswold T, & Messinger OJ (2008). Sampling bee communities (Hymenoptera: Apiformes) in a desert landscape: are pan traps sufficient? *Journal of the Kansas Entomological Society*, *81*(3), 288–301.

Woodcock BA, Edwards M, Redhead J, Meek WR, Nuttall P, Falk S, ... Pywell, RF (2013). Crop flower visitation by honeybees, bumblebees and solitary bees: Behavioural differences and diversity responses to landscape. *Agriculture, Ecosystems & Environment*, *171*, 1–8.

Zink AG, & Rosenheim JA (2004). State-dependent sampling bias in insects: implications for monitoring western tarnished plant bugs. *Entomologia Experimentalis et Applicata*, *113*(2), 117–123.

Appendix 4.1. Summary of attributes of the different methods considered in Chapter 4

Name	Behaviour	Description	Information	Information level	Landscape	Seasonality	Time	Expertise	Lethal	Representiveness	Costs	Pros	Cons	Notes
Flower Insect Timed Counts (FIT Counts)	Foraging	Standardised plot observed for a short period (Watch a 50x50cm patch of flowers for 10 minutes and record how many insects visit)	Abundance	Insect groups/ species	All landscapes	Spring to autumn	Random - can be carried out at any time	Low level: Identification easy enough for volunteers (with little training)	No	All insect groups visiting the chosen flowers	No costs if done without verification, verification would cost ±€5 per visit	Cost-effective method based on volunteers, Easy to use attracts much wider volunteer pool than other surveys (very easy to find volunteers). Submitted directly online so data instantly available. Good way to engage wider public in data collection	Only providing data on broad insect groups (bumble bees, hoverflies, other flies etc.). Works best when volunteers are targeted towards common flowers.	Used in the UK Pollinator Monitoring Scheme
Bait traps	Foraging	Standardized traps to monitor moth populations	Abundance (although the effect of attraction has to be taken into account)	Species	All landscapes	From spring to autumn (but less effective in spring)	Traps emptied and sugar bait added once in 1-2 weeks	Low level: Identification easy enough for volunteers (with little training)	Yes, moths killed by poison (e.g. mixture of chloroform and tetrachloroethane) in the traps	Mainly night-flying noctuid moths, also some nymphalid butterflies	Moderate costs (when based on volunteers), cost estimated at €25/ visit	No electricity needed, and thus traps easier to place anywhere compared to light traps	Attractiveness of sugar baits varies between seasons. Sugar baits attract less species than light traps.	
Yellow Russell traps	Foraging	Standardised traps to monitor pollinators based on attraction of yellow colour	Occupancy (and possibly an indication of abundance, true abundance is difficult for all methods that rely on colour attraction)	Species	All landscapes	From spring to autumn (but traps most effective during spring)	Traps emptied once every 2-3 weeks	High level: (professional) experts needed for the identification of bumble bees, solitary bees and hoverflies	Yes, in the Finnish scheme dichlorvos (DDVP) was used as a poison in the traps to kill the insect samples. Samples frozen.	Bumble bees, solitary bees and hoverflies, but bumble bees collected effectively only during spring; solitary bees generally ineffectively; hoverflies sometimes in large numbers	Moderately costly: traps and the poison are quite cheap; largest cost probably from identification, cost are estimated at €18 per visit	Easy to collect samples, e.g. when transect counts were made at same localities; relatively large catches of bumble bees and hoverflies	The method was destructive for bumble bee populations, because traps are most effective during spring when only queens are active.	The Finnish monitoring schemes were ceased after it became clear that the method was destructive for bumble bees.
Pan traps	Foraging	Standardised traps sprayed with UV-bright paint of different colours (white, blue, yellow) placed at vegetation height	Occupancy (and possibly an indication of abundance, true abundance is difficult for all methods that rely on colour attraction)	Species	All landscapes	Spring to autumn	Depending on research setup, emptied at least weekly.	Collection of data can be done without expert knowledge, identification of samples requires expert knowledge	Yes	Highly debated in literature	Expensive, pan traps themselves are relatively cheap, identification of samples is relatively expensive, the costs per visit are estimated to be €105 per visit.	It was the best performing method in capturing bee species richness in the comparison of methods by Westphal et al. 2008.	Attraction by colour makes this method perform differently in different landscape types	

Name	Behaviour	Description	Information	Information level	Landscape	Seasonality	Time	Expertise	Lethal	Representiveness	Costs	Pros	Cons	Notes
Transect walk (butterflies)	Flight	Standardised transects to monitor butterflies	Abundance	Species	All landscapes	Spring to autumn	Counts once every 1-2 weeks throughout the season (10-20 counts per year depending on the geographic locality)	Low level: Identification easy enough for volunteers (with little training)	No	Only butterflies (and potentially also day-flying moths), but not any other pollinators. Experienced recorders may be able to count both butterflies and bumble bees.	Cheap (when based on volunteers), depending on the exact setup the costs are estimated between €0-21 per visit	Cost-effective method based on volunteers and well-established methodology; annual results available with minimal time-delay	Covers only butterflies and not the most important pollinator groups	National monitoring schemes based on this method already exist in most European countries; also well-established European level collaboration between countries (eBMS)
Transect walk (bumble bees)	Flight	Standardised transects to monitor bumble bees (and the honey bee)	Abundance	Species or similar-looking species (colour) pairs/ groups	All landscapes	Spring to autumn	Counts once a month (6-9 counts per year)	Low level: Identification easy enough for volunteers (with little training). In most countries there are species pairs or groups that cannot be identified at species level in the field.	No	Only bumble bees and the honey bee (+ potentially solitary bees at a group)	Cheap (when based on volunteers), depending on the exact setup the costs are estimated between €0-21 per visit	Cost-effective method based on volunteers and focusing on the most important pollinator group; annual results available with minimal time-delay	Does not cover the more species-rich pollinator groups; in many countries difficult species pairs/groups that cannot be identified to species in the field	National monitoring schemes based on this method already exist in some countries (e.g. Ireland; Britain, Estonia). In Finland pilot scheme started in 2019. In the Netherlands this is included in the regular butterfly monitoring.
Point counts (butterflies)	Flight	Standardised point counts, where butterflies are registered within a radius of, e.g., 25 m around and 5 m above the observer within 15 min	Abundance	Species	Open areas in all landscapes	Spring to autumn	At least 3-7 times a season	Low level: Identification easy enough for volunteers (with little training).	No	Only butterflies (and potentially also day-flying moths)	Cheap (when based on volunteers), no costs unless volunteers are given a net	Not as effective as transects in capturing butterfly diversity.	Not lethal. Easy for volunteers. May be good in areas like gardens with fences where transects are more difficult to use.	Included it since it is used as a complement to transects in the Swedish Butterfly Monitoring Scheme,

Name	Behaviour	Description	Information	Information level	Landscape	Seasonality	Time	Expertise	Lethal	Representiveness	Costs	Pros	Cons	Notes
Flight interception traps	Flight	Standardised tent-like trap used to survey for all flying insects. Insects fly into the tent wall and are funnelled into a collecting vessel attached to highest point.	Abundance and biomass	Species	Open areas in all landscapes	All seasons	Can be active as required depending on the survey, has to be checked at least every two weeks	Expert required for placement, low level for the collection stage, high level to process catch	Yes	Represents multiple groups of pollinators reasonably well	Both traps and data processing are expensive, traps cost between €250 and €500, data processing costs ±€105 per visit	Once placed data are easy to collect; collects across insect groups; this is one of the few methods with minimum collection bias; easy to collect repeat data (as traps are generally installed for a longer period of time)	Can be costly; because the trap does not depend on attraction it is less effective per unit time; finding appropriate locations where the traps are not damaged or interfered with can be an issue; sorting through the large catch for specific components (e.g., pollinators) can be time consuming	We have started an EIP (European Innovation Partnership) project in Ireland on 'Protecting Farmland Pollinators' in 2019. Will use Malaise traps to sample across 40 farms in 2020.
Light traps (with poison)	Flight	Standardised light traps to monitor (macro)moth populations	Abundance and potentially biomass	Species	All landscapes (but needs electricity)	From early spring to late autumn	Traps emptied once a week	Moderate level: Experts needed for identification (macromoths can be identified by volunteers during winter). Identification of micromoths more demanding and unrealistic (not many experts available)	Yes, usually moths killed by poison (e.g. mixture of chloroform and tetrachloroethane) in the traps, but also possible to use (more expensive) freezing traps without any poison. Samples frozen.	Only night-flying moths, not much other pollinators	Only moderately costly, if identification by volunteers (costs from traps, lamps, cables, electricity, poison, checking traps), otherwise expensive, costs estimated at €324 per visit	Reliable, annual abundance estimates for a large number of species. Suitable volunteer experts available.	Moderately costly, and many volunteers needed for identification (which is a lot of work; usually realistic to identify only 1-2 traps per volunteer). Always considerable time-delay in getting annual results completed (due to laborious identification)	National long-term moth monitoring schemes exist at least in Britain, Finland and Hungary.

Name	Behaviour	Description	Information	Information level	Landscape	Seasonality	Time	Expertise	Lethal	Representiveness	Costs	Pros	Cons	Notes
Light traps (without poison)	Flight	Standardised light traps to monitor (macro)moth populations	Occupancy and to some extent abundance. Because moths are released the amount of recapture is unknown, which can disturb abundance estimates. Although experiments show this effect is relatively small.	Species	All landscapes, can be sensitive to light pollution	All seasons	Traps placed in the evening and emptied in the morning. But not placed every day.	Low-Moderate level: In western Europe apps that identify moths from pictures are better than most experts. For eastern Europe not all species are recognised well.	No, moths are released every morning	Not all moths are attracted by light, it appears mainly males are caught.	Cheap (when using volunteers), cost are estimated between 0 and €75 per visit depending on the setup (not including the costs of the trap which is €100)	Cost-effective method based on volunteers, Easy to use, little effort required (easy to find volunteers) When combined with app's (as is currently the case in the Netherlands) data is instantly available.	Largely depends on volunteers Only species attracted by light are observed Possibility of recapture Requires technical infrastructure	In the Netherlands this technique is already being deployed. A large project to get farmers involved, and have them measure the biodiversity of their own farms started in 2019.
Sweep net	Resting	A sweep net is used along a transect and used to capture insects in the vegetation.	Abundance	Species	Open landscapes (not suitable for forest)	Spring to autumn	Between four times a year to every two weeks.	Low, if samples are collected and identified by an expert	yes	Represents multiple groups of pollinators reasonably well	Moderately expensive, when samples are processed by experts. Costs estimated at €165 per visit.	One of the few methods that does not suffer from attraction or observer bias	Depends strongly on weather conditions (as insects hide deeper in the vegetation in poor weather)	
Pheromone trap (moths)	Breeding / surviving winter	A pheromone is used to attract and trap a specific species of insect	Abundance	Species	All landscapes	All seasons (highly species dependent)	Weekly	Low: only one species	Both are possible	Capture only a single species, do not represent pollinators as a whole	Low, traps and pheromones are relatively cheap. Costs are estimated at €15 per visit	Not all species are attracted by light/ colour or sweet scents; some species are hard to monitor using other methods	This method only works for a single species, and becomes quite costly.	In the Netherlands this is often done by moth enthusiasts who enter their data in a central database. This is not an organised scheme, but for some species most of the data comes from these kind of observations.

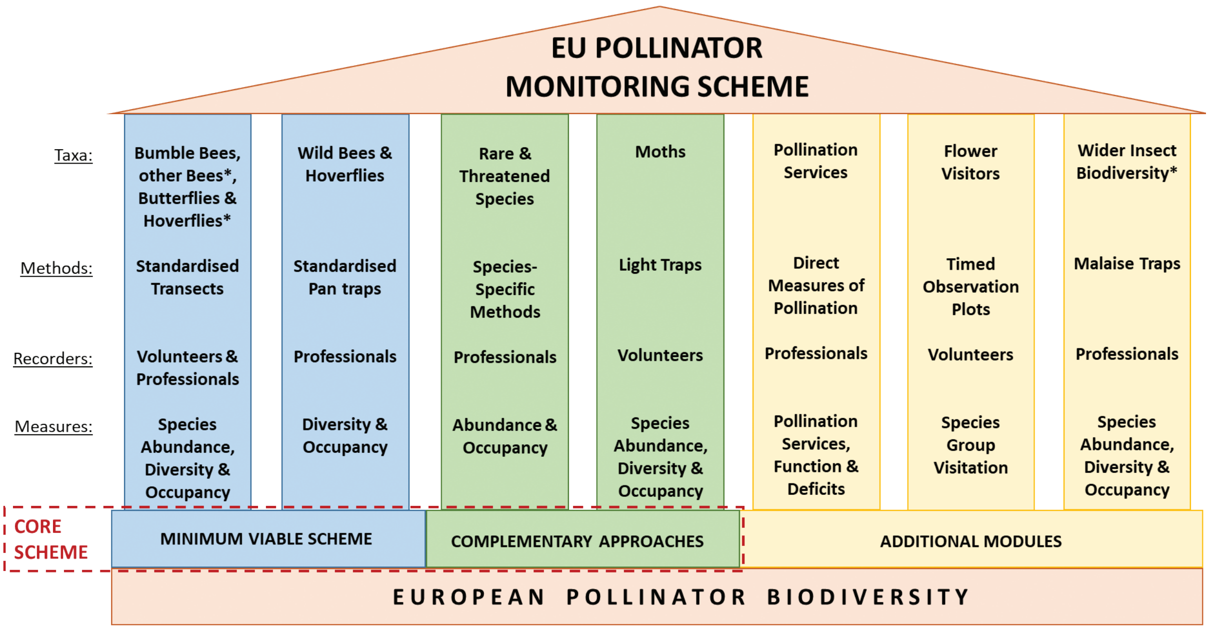
Name	Behaviour	Description	Information	Information level	Landscape	Seasonality	Time	Expertise	Lethal	Representiveness	Costs	Pros	Cons	Notes
Trap nests (solitary bees and wasps)	Breeding / surviving winter	Trap-nests are cavities of different diameters that can consist of: 1. holes drilled in wood, 2. bamboo, reeds and other hollow plant stems, 3. paper or cardboard tubes, 4. cavities made of other materials such as glass or plastic	Abundance	Species	All landscapes	Spring to autumn	Set out in spring and recollected in autumn or left out for several seasons.	Species experts are probably needed for species determination. However, since the number of species occupying these nests is limited it may be possible with a little training also for non-specialists to do the species determination.	Yes, but both are possible	Only cavity-nesting bee and wasp species and their parasites.	Intermediate, the trap-nests can be cheap to make and volunteers can be involved in setting them out and recollecting, but occupied nests need to be stored and the species determination can take quite a lot of time and probably needs to involve species experts. Costs are estimated at €79 per site.	Only catches a small fraction of solitary bees and wasps that are willing to utilise man-made trap-nests as nesting sites. Thus, the possibility to detect differences between habitats using trap-nests is limited. Since the traps need to be out in field during the whole season there is a risk that they are destroyed by people or animals. The handling of collected nests including the storage of occupied tubes and rearing of insects is both time and space demanding.	Capture information on the environment where the bees and wasps actually live (not just passing through), and information on other aspects of the bee community than other methods do, e.g. parasitism, reproduction and pollen use. Thus, trap-nests can be used to gain information on multi-trophic interactions and the needs of the bees and wasps studied. The trap-nests are set out in the spring and recollected in the autumn so the effort using this method will be very low during the field season making it possible to use it in combination with other more field work intense methods.	
Egg monitoring (target one species of moth/ butterfly)	Breeding / surviving winter	Target search for eggs of one species	Abundance	Species	All landscapes	Mostly winter and early spring	Single visit to one location	Low level: only one type of egg has to be recognised	No	Gives a good indication of developments of a single species	Cheap (when based on volunteers), costs are estimated at €3 per visit	Detailed information on development of specific species.	Relatively labour intensive, data quality can vary between observers), Only gives information on single species, Not all species can be monitored this way	This is currently applied for several butterfly species (that are difficult to monitor by a different means) in the Netherlands.

5 Design of the EU Pollinator Monitoring Scheme

The *EU Pollinator Monitoring Scheme* (EU-PoMS) comprises seven modules (see Figure 5.1): a *Minimum Viable Scheme* (MVS, two modules), *Complementary Approaches* (two modules) and optional, *Additional Modules* (3 modules). The *MVS* and *Complementary Approaches* together make up the *Core Scheme* of the EU-PoMS which includes those taxa which are essential to monitor as part of an EU pollinator monitoring scheme (i.e. wild bees, butterflies, moths and hoverflies as well as rare and threatened pollinator species). The *MVS* has two modules, both of which are feasible to implement in the short term, and uses standardised transects and pan traps to provide species abundance, diversity and occupancy data on wild bees, butterflies and hoverflies. The *Complementary Approaches* are two modules within the *Core Scheme*, but which are not yet ready for large-scale adoption because they require some field validation and refinement of methods, in the case of moths, or which cannot otherwise be monitored through a large-scale standardised scheme but instead require species-specific methods in the case of rare and threatened pollinator species. Finally, there are three optional *Additional Modules* of the EU-PoMS which are in addition to the *Core Scheme*, and can provide important measures of pollination services, flower visitors, and wider flying insect biodiversity, if Member States choose to implement them. All three modules require substantial methodological development before they can be adopted as standardised methods as part of the EU-PoMS.

This Chapter describes the power analysis of existing pollinator survey data (section 5.1) which informs on the overall design of the proposed *MVS* (section 5.2), in terms of the number of sites required for a particular level of change detection. We then present two modules, additional to the *MVS*, which can be added to the *Core Scheme* to extend the range of taxa and measures which can be implemented on top of the *MVS*; these include moths (section 5.3.1) and rare and threatened species (5.3.2). Next we present the three *Additional Modules* which are optional: pollination services (section 5.4.1), flower visitation (section 5.4.2), moths (section 5.4.3), and wider biodiversity (section 5.4.3). The various costs of establishing and implementing the *MVS* and additional modules at the Member State and EU level are tentatively estimated in section 5.5. Opportunities are explored for linking the proposed *MVS* to existing pollinator monitoring schemes (section 5.6).

Figure 5.1. Overview of the proposed **EU Pollinator Monitoring Scheme** (EU-PoMS). The overall scheme comprises a number of components: the Core Scheme are those taxa which are essential to monitor as part of an EU Pollinator Monitoring Scheme (i.e. wild bees, butterflies, moths, hoverflies, as well as rare and threatened pollinator species). Within the Core Scheme is a **Minimum Viable Scheme** (MVS) which is feasible to implement in the short term and comprises two modules which use standardised transects and pan traps to provide species abundance, diversity and occupancy data on wild bees, butterflies and hoverflies (section 5.2). **Complementary Approaches** are needed for moths (5.3.1), and for targeting rare and threatened species (5.3.2) which cannot otherwise be monitored through a large-scale standardised scheme. There are three **Additional Modules** which are optional and could provide important measures of pollination services (5.4.1), flower visitors (5.4.2), and wider flying insect biodiversity (section 5.4.3). For each component of the EU-PoMS the main target taxa, sampling methods, type of recorder, and output measures are given. * indicates that for these groups only a proportion would be identified to species; a number of important details and caveats for all elements presented in this overview are addressed in detail in the main report text.



5.1 Power analysis and detection level

This section addresses the question of what is a sufficient sample size to detect changes in pollinator diversity and abundance for the proposed scheme's target taxa (see section 3.2) and sampling methods (see section 4.2). A power analysis is employed to do this, and the results feed into section 5.2 on our proposed Minimum Viable Scheme (MVS).

5.1.1 Criteria for effective monitoring programme as applied in some Butterfly Monitoring Schemes

Buckland and Johnston (2017) define five criteria for a well-designed monitoring programme for biodiversity assessment in large regions (e.g. pollinating insects across Europe):

- Representative sampling locations;
- Sufficient sample size;
- Sufficient detections of target species;
- Representative sample of species (or all species);
- A temporal sampling scheme designed to aid valid inference.

Representative sampling locations are required to ensure that estimated trends in pollinator populations are representative of the region of interest and not biased towards particular habitats or locations. In an ideal sampling design, representativeness is achieved by simple random or stratified-random site selection (Buckland et al. 2012). Where representativeness is not achieved though allocation of samples, model-based representativeness is an alternative approach whereby samples are reweighted such that their contribution to the overall trend estimate is representative. For example, reweighting can account for uneven sampling of habitats across a region, as applied for some Butterfly Monitoring Schemes (van Swaay et al. 2008), or to account for differences between countries in the proportion of an overall population, as used to calculate bird trends for Europe (Gregory et al. 2005).

Sufficient sample size is required to estimate biodiversity trends with reasonable precision. A power analysis is typically used to inform sample sizes required to detect change with a given level of precision. This section primarily focuses on the second of these criteria (sufficient sample size), but these are dependent on choices made for sampling methods and how they are deployed. Sampling methods need to be effective in different habitats and regions.

5.1.2 Estimating the number of sampling sites needed to detect pollinator trends

Appropriate design and statistical power are essential to any biodiversity monitoring scheme if the resulting data are to be widely accepted as credible indicators of change. This section describes a power analysis, with the main aims to:

- Estimate the minimum levels of replication (principally the number of sites) required to detect changes in abundance and species richness of the different key pollinator groups (bumble bees, solitary bees, butterflies and hoverflies) sampled using either pan traps or transect methods;
- Identify realistic scenarios to investigate, including the number of years of monitoring, the number of sites monitored, the range of initial likely count values, the sizes of decline in pollinator species abundance, richness or service provision that should be detectable, and the amount of power with which a particular change should be detected.
- Monitoring pollinators for the whole of the Europe and for individual Member States is the focus of this work. The objective of the monitoring is to describe the trend in pollinators for the EU; schemes to estimate the drivers of trends will have different optimal survey designs (see section 6.1.4). This section therefore considers a surveillance monitoring scheme (Wintle et al. 2010) as its primary focus.

5.1.2.1 Response variables and scenarios of interest

Simulations were run to ascertain the power to detect declines according to a set of variable input parameters. Parameters were selected to be as realistic as possible for pollinator groups, based on empirical field data. We focussed on variables representing the abundance (counts of individuals) and species richness (numbers of species) where available for four key groups generated by either pan trapping or fixed transect methods: bumble bees, solitary bees, hoverflies and butterflies.

The final set of variables and scenarios tested were:

- Number of sites: 10, 25, 50, 100, 200, 500, 1,000
- Number of years: 10

- Initial abundance (counts per site) for pollinators: 1, 10, 50, 100, 200
- Initial service and deficit values for pollination: ranging from 5% to 30% depending on crop
- Percentage decline over 10 years (%): 0, 1, 5, 10, 30, 50 (equating to annual declines of 0, 0.1, 0.5, 1.0, 3.5 and 6.7% respectively)
- Rates of decline were assumed to be constant over the 10-year period, and all sites were assumed to be visited each year.

A measure of sampling intensity (number of visits per year) was incorporated into our preliminary power analyses, but this created an impractical number of scenarios. Instead, we considered the initial count as the sum of counts at a typical site throughout a year, i.e. counts were summed across sampling visits within a single year and across any replicate sampling points within visits. This circumvents the issue that different species have different seasonal distributions (i.e. flight periods); otherwise a separate power analysis would have been required for each species/species group. There are also convergence issues with models that have an initial count of less than one as typically occurs with individual sampling visits for many pollinator groups (i.e. a simulated decline from a mean count of less than one is very close to the boundary of zero).

5.1.2.2 Pollinator datasets to inform design of a monitoring scheme

A review of available data on pollinator populations across Europe identified 77 candidate datasets, covering a range of sampling methods (Table 5.1) across the continent (Figure 5.2). Note that some datasets included multiple methods; the sum of methods x datasets being 138. Sixteen of these datasets were evaluated in further detail (Table 5.2). There is no dataset from sampling pollinator abundance and species richness in a consistent way across Europe.

Table 5.1. Number of candidate datasets by sampling method. Some datasets were recorded using > 1 method (Sum of methods > sum of entries)*

Method*	Number of datasets
Hand / Sweep net	5
Hive monitoring	4
Suction traps	1
Timed counts	14
Transect walks	29
Traps* (light traps, pan traps, Russell traps, Malaise traps, moth traps)	11
Various (standardised and non-standardised but information not available)	1
Others (photo, video, ad hoc sightings, casual sightings)	16
Not available	5
Citizen Science / Volunteers	52

We reviewed the suitability of existing datasets to infer the statistical power of pollinator monitoring schemes. We prioritised datasets comprising more than 10 separate sampling sites, each sampled for at least 2 years. Ideally, each sampling site was sampled more than once within each year so that the annual totals cover the seasonal flight period or crop flowering period. Datasets for our recommended sampling methods (pan traps and transects) were further prioritised, as was an attempt to cover the range of bioclimatic regions of Europe (Table 5.2). A subset of 9 dataset were analysed in detail and are described below (Location – data provider):

1. **Spain – Bartomeus and Molina:** EBD-BeeFun project[1]: Plant-pollinator standardised transects surveyed for 30 minutes, along 16 sites in Mediterranean scrubland in South Spain. Each site was visited 7 to 8 times per year, in 2015 and 2016. Taxon groups represented include bumble bees, hoverflies and solitary bees.

1 https://cordis.europa.eu/project/id/631653/reporting

Figure 5.2. Number of candidate datasets by country.

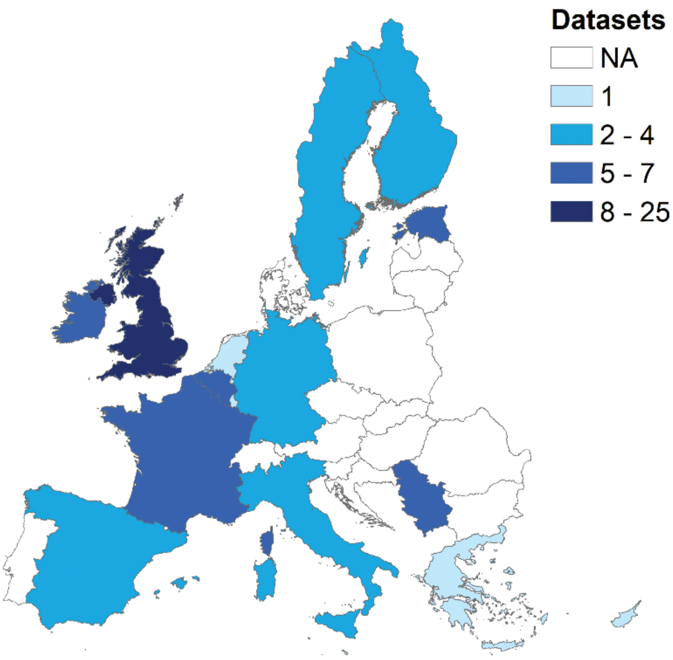


Table 5.2. Summary of 16 candidate datasets to inform design of an EU Pollinator Monitoring Scheme.

Region	Years	Methods	Selected sites	Annual visits / site	Contributor name	Notes
Spain	2	Transects	16	6 to 9	Ignasi Bartomeus and Curro Molina	Unpublished data from project BeeFun: Pollinator responses to global change and its implications for ecosystem function (2014–2018) Marie Curie Actions – FP7-PEOPLE-2013-CIG (PCIG14-GA-2013-631653).
Greece	3	Pan traps	13	3	Theodora Petanidou and Georgios Nakas	Unpublished, used within a PhD thesis (G. Nakas) implemented within the project SERAPIS (funding body: Hellenic Foundation for Research and Innovation)
Germany	>=4	Combined flight traps	95 (across 6 landscapes)	6	Mark Frenzel and Oliver Schweiger	Data organised under the project umbrella of "TERENO (Terrestrial Environmental Observatories)" funded by the German Helmholtz Association
France	1 to 3	Pan traps	18 (out of the original 20)	4 to 11	Bernard Vaissière	Data collected under the Apiformes network in France, funded by Pollinis and available in Féon *et al.* (2016).
Serbia	2	Transects	12	1 to 3	Ante Vujic and Marina Janković	Unpublished data from ongoing PhD (M. Janković)
United Kingdom	2	Pan traps	25	(>=) 2	Claire Carvell	UK PoMS: Data provided from project BE0125 (Establishing a UK Pollinator Monitoring and Research Partnership (PMRP)) funded by the Department for Environment, Food and Rural Affairs (Defra), Scottish Government, Welsh Government, JNCC, UK Centre for Ecology & Hydrology and other project partners.

Region	Years	Methods	Selected sites	Annual visits / site	Contributor name	Notes
United Kingdom	2	Pan traps and fixed transects	96	3	William Kunin	Data from the UK Insect Pollinators Initiative project, “AgriLand: Agriculture and land-use effects on pollinators” (BB/I000364/1)
United Kingdom	4	Fixed transects	8	5	Claire Carvell	CEH BigBee: Data provided from project BD1625 (Restoration and Management of Bumblebee Habitat in Agricultural Landscapes), funded by the Department for Environment, Food and Rural Affairs (Defra), and Natural England, Peterborough, UK.
Several, Butterfly Monitoring Schemes	10	Transects	>3,000	Average of 14	David Roy	Data from Butterfly Monitoring Schemes in a number of member states, accessed under licence from the European Butterfly Monitoring Partnership*.

* https://butterfly-monitoring.net/ebms

2. **Greece – Petanidou and Nakas:** 13 sites in Chios, surveyed with pan traps in 2013, 2014 and 2015. Data refer to naturally occurring pollinator species (Lepidoptera, Hymenoptera, Diptera and Coleoptera).

3. **Germany – Schweiger and Frenzel:** TERENO project[2]. Wild bee monitoring in 6 agriculturally dominated landscapes of Saxony-Anhalt, each of 4 x 4 km, from 2010 to 2014. Sampling was conducted with combined flight traps: traps consist of a yellow funnel (25 cm diameter) filled with water (preserving agent added) and two Perspex windows mounted in a way that they are crossed in the centre. Within each square km of a site one trap was placed at ecotones between semi-natural habitats and agricultural fields (16 traps per site). Traps were operated in late spring-early summer (three sampling rounds) and late summer (three sampling rounds).

4. **France - Vaissière:** Apiformes network of French agricultural schools, in which at least one teacher volunteered to be trained to identify bees to the genus. Pan traps were used to sample wild bees. Specimens were identified to the species level by experts. Each site was sampled usually once a month, during spring, summer, and early autumn. The dataset used for the analysis are available in the Online Resource 13 of Le Féon et al. (2016), collected between 2009 and 2011. From the original dataset, we retained data from 18 sites (criterion: site surveyed for at least 2 years), for a total of 45 samples (out of the original 70).

5. **Serbia – Vujic and Janković:** 12 localities surveyed for hoverflies, by means of transect walks. Each locality was surveyed between 1 and 3 times during spring, summer and early autumn, for at least two years between 2015 and 2019, with most surveys carried out between 2016 and 2018. Specimens were identified to species level.

6. **UK – Kunin:** IPI AgriLand[4]: Systematic surveys sampling pollinators across 96 predominantly agricultural sites (64 in England and 32 in Scotland) conducted during 2012 and 2013 between April – September (3 survey visits per year). Data from pan traps (to species level) and fixed transects (to pollinator group level) were used.

7. **UK – Carvell: CEH BigBee[5]:** Systematic surveys sampling bumble bees across 8 agricultural sites in England (along a gradient of landscape complexity) conducted during 2004 – 2007 between May-September (5 monthly visits per year). Fixed transects of 2 x 100 m were conducted on non-crop habitat along 16 randomly allocated field boundaries at each site (Carvell et al. 2011).

8. **UK – Carvell:** Pollinator Monitoring Scheme (PoMS)[6]: Systematic surveys using pan-traps to sample insects from a set of 75 1 km squares in England, Scotland and Wales. 1 km squares were randomly allocated within cropped and non-cropped land. The data from two consecutive years and from surveys in the same months were available from 25 of these 1 km square sites.

2 https://www.ufz.de/index.php?en=37279
3 https://static-content.springer.com/esm/art%3A10.1007%2Fs10841-016-9927-1/MediaObjects/10841_2016_9927_MOESM1_ESM.xlsx
4 https://www.agriland.leeds.ac.uk/
5 https://webarchive.nationalarchives.gov.uk/20140711140318/http://www.ceh.ac.uk/sci_programmes/bumblebeeresearch.html
6 https://www.ceh.ac.uk/our-science/projects/pollinator-monitoring

9. **Butterfly Monitoring Schemes[7], collated via the eBMS partnership – Roy:** Long-term monitoring scheme for butterflies using fixed transects on volunteer-selected sites across European schemes. Data was restricted to 2010 onwards and for site-species-year combinations where more than 50% of the flight period was sampled, and where sites were recorded for all years between 2010 and 2017. Analysis was restricted to 21 species with good coverage of sites and monitoring schemes. This comprises 74,296 annual totals (site indices) as a combination of site, species and year. A total for 'all butterflies' was also calculated, summing counts for individual species; giving 5,208 combinations of sites and years.

5.1.2.3 Determining realistic variance parameters for initial counts of abundance or species richness and trends over time

The mixed effects models on which the power analyses for the pollinator abundance and species richness data were based on the assumption of a Poisson response, as follows:

$$\log\left(\mu_{i,j}\right) = \beta_{0,j} + \beta_{1,j}\ \mathrm{Year}_i$$

Where:

- $\mu_{1,j}$ refers to the expected species group count at time i, site j
- $\beta_{0,j} = \beta_0 + \gamma_0$
- $\beta_{1,j} = \beta_1 + \gamma_1$
- $\gamma_0 \sim N\left(0, \sigma^2_{\beta_0}\right)$
- $\gamma_1 \sim N\left(0, \sigma^2_{\beta_1}\right)$

and $C_{i,j} \sim \mathrm{Poisson}\left[\exp\left(\beta_{0,j} + \beta_{1,j}\mathrm{Year}_i\right)\right]$

$\mu_{1,j}$ are the expected counts at time *i* and site *j* on the assumption of a Poisson distribution; $\beta_{0,j}$ is the site-specific intercept term and is made up of the overall mean intercept (β_0) across all sites, and a random term (γ_0), which indicates how far the intercept of each site is different from the overall mean of all intercepts; $\beta_{1,j}$ is the site-specific slope term (how much the counts change over time, i.e. site trend) and is made up of the overall mean slope (β_1) and a random term (γ_1), which indicates how far the slope for each site is different from the overall mean of all slopes; and $C_{1,j}$ is a random variable for the counts, indicating they are Poisson distributed with parameter.

$$\mu_{i,j} = \exp\left(\beta_{0,j} + \beta_{1,j}\mathrm{Year}_i\right)$$

To standardise the power analysis, the counts $C_{1,j}$ are simulated as annual totals and take no account of seasonal patterns in abundance of insects or sampling methods that deploy several sub-samples (e.g. a series of pan traps within a site). The complexity of simulations with multiple samples within a season (e.g. monthly counts) was not feasible due to the technical challenge of fitting more complex statistical models as well as the lack of consistency in empirical data in the number of samples per year (Table 5.2).

Given the inherent variation in abundance and detectability of pollinating insects, it was essential to account for variability in the starting abundances and trends over time for the different response variables. This step helps to ensure greater realism, particularly where the scope of a monitoring scheme covers a large geographic area, across which the drivers of change for particular species or groups may vary, and species exist at different abundances. A key challenge for such an approach is to derive realistic measures of variability to use in analyses. Ideally, pilot studies would be conducted, although existing datasets using a similar methodology to the proposed schemes are commonly used (LeBuhn et al. 2013).

7 https://butterfly-monitoring.net/

All count data were modelled with the Poisson distribution, which has a log link function. Count data are often over-dispersed and zero-inflated. To take account of this, Negative binomial mixed effects models can be used; however, simulations with the dispersion parameter have proved difficult to control and may be explored in further development work. Most of the power analysis presented here is at the level of higher taxonomic groups (i.e. all hoverflies), with few zero values within the datasets. Zero-inflation is therefore not considered a major factor to account for. Over-dispersion would typically increase the number of sites required; therefore the estimate of power is over-optimistic in cases with high over-dispersion.

We ran Poisson generalised linear mixed models (GLMMs) for the different response variables and datasets described above (with site as random effect; intercept and slope (by year), and year as a fixed effect). This produced relatively high random effects standard deviation values representing both the intercept (spatial variation) and slope (temporal variation across years) (Tables 5.3–5.6).

5.1.3 Results of the power analysis

We have combined results of the Poisson linear mixed effects models giving typical initial counts and variance parameters for a range of key pollinator groups with the outputs of the power simulations, to provide summary estimates of the numbers of sites required to achieve power greater than 80% to detect declines of 10%, 30% and 50% over 10 years (Tables 5.3–5.6). Power greater than 80% is considered a sufficient level to detect an effect if it truly exists, and is typically used in similar assessments (e.g. Roy et al. 2007).

The random effects variance combination that best reflected the empirical field data on pollinators was a scenario with intercept SD = 0.5 and slope SD = 0.1. The Figures below (5.3 and 5.4) visualise the power from Tables 5.3–5.6 with initial mean counts of 10 and 100. The curves show that only a minor increase in power is generated by the higher initial count values, with the number of sites and sensitivity of declines to be detected having a greater influence on statistical power (see Table 5.7 for the full set of estimated power calculations under the different simulations).

The following tables provide parameter estimates from a Poisson mixed effects model, estimating the effect of year on annual abundance (counts) or species richness, with site as a random effect. Annual counts per site represent totals for each group for each dataset and sampling method (pan traps or transects). The sampling intensity varies between each

Figure 5.3. Power curve for initial mean count = 10, with random effects intercept SD = 0.5 and random effects slope SD = 0.1, from Poisson mixed effects model, with varied levels of number of sites and percentage declines over ten years. The horizontal red line illustrates power at 80%.

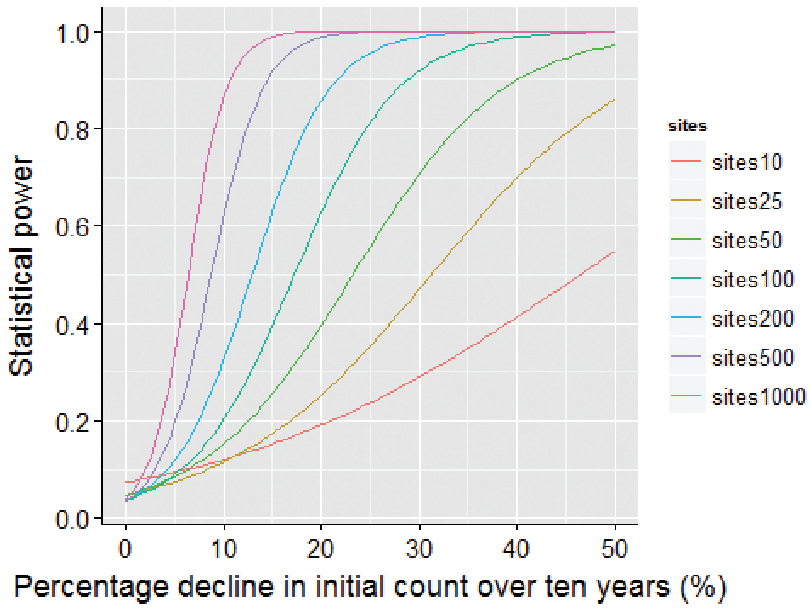


Figure 5.4. Power curve for initial mean count = 100, with random effects intercept SD = 0.5 and random effects slope SD = 0.1, from Poisson mixed effects model, with varied levels of number of sites and percentage declines over ten years. The horizontal red line illustrates power at 80%.

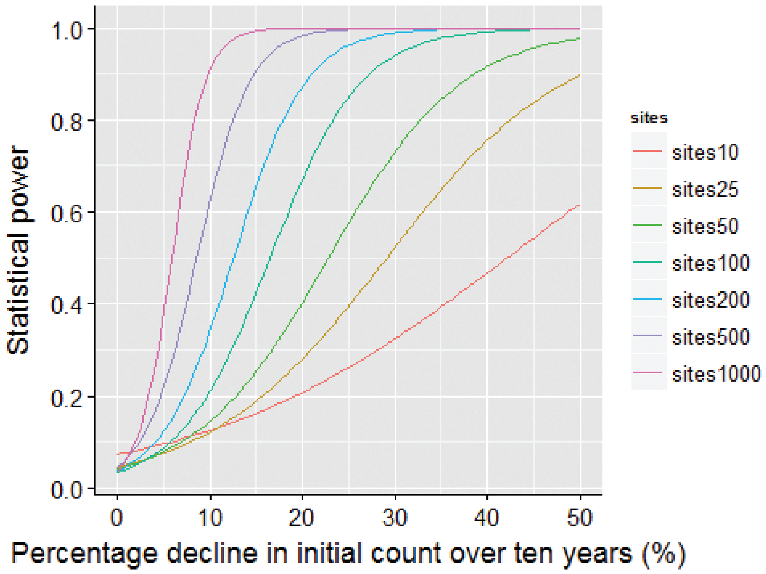


Table 5.3. Variability in abundance of pollinator groups sampled by Pan Traps.

Measure	**Dataset**	**Typical initial annual count per site (mean and variance)**	**Estimated variability (Standard Deviation)**	
			Intercept	**Slope (years)**
All bees	UK (PoMS)	19.52 (228)	0.85	0.86
Bumble bees	UK(IPI AgriLand)	14.3 (245)	0.88	0.91
Bumble bees	Greece	1.33 (3.54)	0.50	0.07
Bumble bees	France	1.75 (3.68)	1.142	0.826
Bumble bees	Germany	16.29 (231)	0.63	0.16
Bumble bees	UK (PoMS)	7.26 (49.87)	1.01	1.40
Solitary bees	UK (IPI AgriLand)	12.5 (625)	1.93	1.24
Solitary bees	Greece	268.8 (36567)	0.46	0.43
Solitary bees	France	62.48 (2216)	0.916	0.576
Solitary bees	Germany	93.62 (6645)	0.81	0.18
Solitary bees	UK (PoMS)	9.96 (161.79)	1.14	0.81
Hoverflies	UK (IPI AgriLand)	76.9 (13414)	1.23	0.92
Hoverflies	Greece	9.39 (48.6)	0.42	0.38
Hoverflies	UK (PoMS)	31.46 (4331)	0.77	1.19
Episyrphus balteatus	UK (PoMS)	6.4 (482.65)	1.63	2.07
Syrphus ribesii	UK (PoMS)	3.58 (238.82)	12.81	3.05
Lasioglossum glabriusculum	France	4.11 (139.73)	12.81	3.05
Lasioglossum malachurum	France	12.27 (411.6)	1.68	0.79
Andrena nigroaenea	Germany	18.8 (573.82)	1.18	0.24

Table 5.4. Variability in species richness of pollinator groups sampled by Pan Traps.

Measure	Dataset	Typical initial species richness per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Bumble bees	UK (IPI AgriLand)	3.82 (3.83)	0.21	0.02
Bumble bees	Greece	0.67 (0.23)	0	0
Bumble bees	France	1.30 (1.61)	0.652	0.276
Bumble bees	Germany	5.63 (6.86)	0.28	0.02
Solitary bees	UK (IPI AgriLand)	4.41 (33.36)	1.38	0.46
Solitary bees	Greece	17.54 (103.41)	0.17	0.003
Solitary bees	France	17.45 (22.63)	0	0.083
Solitary bees	Germany	23.05 (104.85)	0.42	0.06
ALL bees	UK (IPI AgriLand)	8.64 (50.45)	0.77	0.28
All bees	Greece	18.64 (25.96)	0.163	0.001
All bees	France	18.75 (25.96)	0.074	0.054
All bees	Germany	29.61 (117.94)	0.34	0.05
Hoverflies	UK (IPI AgriLand)	10.20 (26.29)	0.37	0.09
Hoverflies	Greece	3.87 (4.54)	0	0

Table 5.5. Variability in abundance of pollinator groups sampled by Transects. See Annex A for results for individual butterfly species. Note that values for butterflies are based on totals for all species.

Measure	Dataset	Typical initial annual count per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Bumble bees	UK (IPI AgriLand)	7.35 (110)	1.18	1.24
Bumble bees	UK (CEH BigBee)	132.3 (7659)	0.69	0.20
Solitary bees	UK (IPI AgriLand)	1.37 (10.1)	2.02	1.41
Hoverflies	UK (IPI AgriLand)	19.2 (1160)	1.56	1.53
Butterflies	German BMS	780.5 (707241.24)	0.92	0.07
Butterflies	Catalonia BMS	1915.8 (2535030.12)	0.76	0.07
Butterflies	Finland BMS	2144 (3044457.25)	0.63	0.05
Butterflies	Ireland BMS	894.8 (406850.01)	0.63	0.05
Butterflies	Netherlands BMS	762.5 (443890.41)	0.74	0.06
Butterflies	UK BMS	1681 (3331022.75)	0.81	0.07
Bombus lapidarius	UK (CEH BigBee)	36.8 (1099)	0.76	0.29
Bombus hortorum	UK (CEH BigBee)	16.3 (412)	0.94	0.31

Table 5.6. Variability in the species richness of pollinator groups sampled by Transects. Note that butterfly species richness is only based on the 21 focal species (section 5.1.2.2).

Measure	Dataset	Typical initial species richness per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Bumble bees	Spain	0.6 (0.25)	0	0

Measure	Dataset	Typical initial species richness per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Solitary bees	Spain	12.13 (22.05)	0	0.24
All bees	Spain	13.73 (23.31)	0	0.22
Hoverflies	Spain	1.93 (1.86)	0.17	0
Butterflies	German BMS	7.91 (25.89)	0.88	0.001
Butterflies	Catalonia BMS	10.53 (15.63)	0.48	0.001
Butterflies	Finland BMS	3.93 (3.02)	0.43	0.006
Butterflies	Netherlands BMS	11.55 (22.63)	0.45	0
Butterflies	Ireland BMS	6.23 (10.31)	0.66	0.01
Butterflies	UK BMS	11.47 (27.34)	0.74	0.01

Table 5.7. Power simulations under varying initial mean abundance counts and percentage changes over a 10-year period for 10, 25, 50, 100, 200, 500 and 1,000 sites, with random effect intercept SD = 0.5; random effect slope SD = 0.1. These were modelled under a Poisson GLMM with random intercepts and slopes (across years), with site as the random effect. This model assumes a single total count per year, which may be achieved via multiple sampling visits to a site. All scenarios were run with 1000 simulations. Power greater than 80% (highlighted in bold) is considered sufficient to detect an effect if it truly exists.

Initial annual count per site	Percentage change over ten years (%)	Estimated power						
		10 sites	25 sites	50 sites	100 sites	200 sites	500 sites	1,000 sites
1	0	0.087	0.068	0.085	0.132	0.166	0.168	0.138
1	1	0.081	0.068	0.097	0.141	0.194	0.173	0.140
1	5	0.082	0.063	0.101	0.143	0.197	0.245	0.265
1	10	0.094	0.097	0.121	0.208	0.293	0.413	0.609
1	30	0.169	0.240	0.436	0.690	**0.903**	**0.998**	**1**
1	50	0.322	0.603	**0.887**	**0.994**	**1**	**1**	**1**
10	0	0.091	0.065	0.070	0.050	0.062	0.038	0.047
10	1	0.100	0.077	0.082	0.056	0.058	0.056	0.059
10	5	0.098	0.080	0.074	0.081	0.100	0.178	0.326
10	10	0.089	0.086	0.116	0.177	0.296	0.625	**0.869**
10	30	0.244	0.409	0.674	**0.924**	**0.999**	**1**	**1**
10	50	0.580	**0.899**	**0.997**	**1**	**1**	**1**	**1**
50	0	0.092	0.056	0.059	0.042	0.063	0.058	0.047
50	1	0.090	0.051	0.049	0.054	0.044	0.050	0.058
50	5	0.103	0.065	0.069	0.079	0.118	0.201	0.347
50	10	0.116	0.091	0.126	0.212	0.305	0.662	**0.920**
50	30	0.257	0.436	0.703	**0.947**	**0.999**	**1**	**1**
50	50	0.626	**0.922**	**0.996**	**1**	**1**	**1**	**1**
100	0	0.104	0.062	0.069	0.047	0.051	0.056	0.049
100	1	0.085	0.066	0.064	0.061	0.056	0.055	0.053
100	5	0.097	0.076	0.061	0.072	0.120	0.217	0.369
100	10	0.098	0.125	0.119	0.181	0.312	0.623	**0.915**

Initial annual count per site	Percentage change over ten years (%)	Estimated power						
		10 sites	25 sites	50 sites	100 sites	200 sites	500 sites	1,000 sites
100	30	0.276	0.445	0.708	**0.950**	**0.999**	**1**	**1**
100	50	0.651	**0.943**	**0.998**	**1**	**1**	**1**	**1**
200	0	0.115	0.067	0.052	0.047	0.053	0.051	0.039
200	1	0.085	0.075	0.058	0.064	0.052	0.074	0.055
200	5	0.112	0.073	0.074	0.093	0.131	0.209	0.378
200	10	0.124	0.105	0.127	0.178	0.321	0.661	**0.899**
200	30	0.245	0.465	0.726	**0.954**	**1**	**1**	**1**
200	50	0.626	**0.933**	**0.999**	**1**	**1**	**1**	**1**

dataset, for example the number of sampling occasions per year and length of transect. Means and SD variance parameters are estimated.

5.1.4 Discussion, practical conclusions and caveats

5.1.4.1 Discussion of findings and implications for scheme design

On average, variance is higher for the abundance variables than for species richness. This is expected given that numbers of individual bees, butterflies or hoverflies are more likely to vary between sites and years than the presence of particular species. Within the largest systematic dataset tested (IPI AgriLand) that included multiple sampling methods, variance tended to be higher using transect methods than pan traps. The site factors affecting variance are not investigated in detail here.

Where variance parameters from the real data were close to those used in the simulations, power analyses suggested that around 100 sites per Member State should provide sufficient power (>80%) to detect a 25–30% decline over 10 years for species or pollinator groups with initial counts of 10–200 individuals per site. Higher numbers of sites are likely to be required (more than

Eucera dimidiata, Nicolas J. Vereecken

1,000) if lower rates of decline are to be detected (≤10% over 10 years), particularly for species or groups occurring in small numbers. Estimates of decline in insect populations vary widely, with a recent global meta-analysis of 166 long-term surveys of insects finding an average decline of terrestrial insect abundance of approximately 9% per decade (van Klink et al. 2020). Large sampling networks per member state would be required to detect these levels of change.

Obtaining initial annual counts of at least 10 individuals (or species) per site seemed to give roughly equivalent power to that achieved with initial counts of up to 100 or sometimes 200 individuals. This suggests that sampling intensities may be sufficient if capturing at this lower end of count values (as might occur, for example, in northern Europe or in areas with less stable weather conditions), although methods would need to be robust enough to ensure consistency between sites and reduce variance where possible. Only species or groups at typically very low annual counts of <10 may be considered beyond the scope of achieving high power at the likely scale of a monitoring scheme implemented across Europe.

Patterns of temporal variation across months can point to the optimal timing of visits within years to achieve the required initial counts for each of the different pollinator groups. For example, sampling focussed from June to August would likely be suitable for bumble bees and hoverflies, but for solitary bees sampling in the early part of the season (March/April/May) is likely to be essential in many parts of Europe, such as the Mediterranean.

Detecting 10% or lower proportional declines over 10 years (approximately equating to a 1% annual decline) by any of the tested methods and even with initial site counts of 200 insects would require at least 1,000 sites per Member State, according to simulations using viable variance parameters that were closest to those generated from real data in our analyses.

Given the inherent variability in insect populations, detecting a 10% decline over 10 years is likely to be unrealistic, hence what level of change do we want to be able to detect? LeBuhn et al (2013) reported >90% power to detect 1% annual declines in total abundance and species richness of all bees. A survey of northern and western European experts on the design of research networks able to answer key research questions (Breeze et al. 2020) offers an extremely valuable insight into this question. Experts (on average) indicated that a 5% annual detection rate (equivalent to a 40% decline rate over 10 years) for each pollinator response variable would be an ideal standard for a network designed to capture pollinator trends

There is no dataset on pollinator populations collected in a systematic way across Europe. Nor are any datasets available that exactly match the recommended sampling methods for an EU Pollinator Monitoring Scheme, e.g. 10 pan trap sets per site with concurrent transects for all pollinating insect groups. Ideally, power analysis would be based on the sampling methods to be deployed and the statistical models to be applied for estimating trends. Although we have analysed the most comprehensive datasets available for insect pollinators in Europe, all are from a single region within a single Member State, are typically from short-term sampling (2–3 years) and are spatially biased in their geographic coverage (both within and between Member States). Therefore, extrapolating to provide recommended sampling sizes required at the EU level is highly uncertain.

In summary, given these constraints and the variability in pollinator abundance from available empirical data, and lack of data from many parts of Europe, we rely heavily on expert opinion in recommending that a *minimum* network of 2,000 to 3,000 sites should be implemented across Europe. On the scale of the whole EU, a network of this size is estimated to provide power of >80% to detect changes of ~10% in abundance and species over 10 years for major groups (bumble bee, hoverflies, solitary bees and butterflies). For individual Member States with a network of ~100 sites, we estimate good power to detect changes of ~30% over 10 years for major pollinator groups and some individual species.

Achieving greater confidence in these recommendations requires more comprehensive data to be collected, as proposed in a pilot phase prior to full implementation of a scheme across all Member States. Whatever the size of the sampling network for the entire EU, we recommend that sites are allocated in proportion to the land area of Member States, adjusted to ensure a minimum number of sites per country. This is required to cover the geographic variability in climate, landscapes and habitat across the continent

5.1.4.2 Caveats

Any power analysis can only review a small number of the potential scenarios that might occur in reality; the central challenge is to ensure that all potential sources of variability are captured to some extent. The omission of large sources of variance in power analyses may lead to overly optimistic expectations. Here, we have sought to extend the standard approach to power analyses to incorporate two key sources of potential variability that might occur in a monitoring scheme for pollinators: the potential for variance in the rate of change in abundance or species richness and the potential for variance in starting values across space. As the modelled variance parameter values from our 2 to 4 year datasets were high and often produced simulations with extremely large counts over the 10-year period, outputs of the power simulations using more viable variance parameters should be treated with caution.

The power analysis could be extended as further datasets become available (section 9.1). Further work could, however, usefully expand the range of simulations between 200 to 500 sites and include initial counts of 5 insects; explore the use of alternative model structures to better account for over-dispersion in the counts (e.g. Negative Binomial distributions) and explore reduced-effort approaches or alternate years' sampling at given sites within the overall framework. The simulations do not include a residual error term and therefore assume a constant measurement error. Measurement error in this context includes a range of factors, including incomplete detection, weather during sampling and difference in recorders.

5.2 Proposal for sample sites for the Minimum Viable Scheme (MVS)

This section uses the outputs of the power analysis (section 5.1) to develop the design of a scheme with representative sampling locations, sufficient sample size and sufficient detection of target species.

5.2.1 Numbers of sites and allocation across the EU

The power analysis of available empirical data suggests a network of *minimum* 2,000 to 3,000 sites should be implemented across Europe to assess pollinator populations. All sites would be monitored every year. Based on an average of 75 sites per Member State, an allocation in proportion to land area of Member States, adjusted to ensure a minimum of sites per country, would provide representative coverage. Options for allocation of sites by Member State and associated costs are considered in detail within section 5.5. Figures for the number of survey sites per Member State are provisional. We recommend that a fuller assessment is made to account for habitat diversity and heterogeneity within Member States, which is likely to affect spatial variability in pollinating insects (section 9.1.1). Ideally, pilot field sampling should be undertaken to provide a more comprehensive assessment of variability across landscapes and climatic zones across Europe.

5.2.2 Existing site networks for co-location of pollinator surveys

Within each Member State, the location of sites to monitor pollinator populations should ideally not be overly biased by specific regions, habitats or location of recorders. A random or stratified-random process to determine the location of sampling sites is therefore recommended. Where such a design-based approach is not possible, model-based representativeness is an alternative approach whereby samples are reweighted such that their contributions to the overall trend estimate are representative. We evaluated the coverage of candidate monitoring networks in Europe for co-aligning pollinator surveys. The overarching benefits of co-locating pollinator surveys with an existing monitoring scheme or schemes include:

- Obtaining additional data on land cover or other environmental factors that can help interpret pollinator data, including correlation and possible links with dynamics of other taxa (e.g. floral resources);

Andrena potentillae, Nicolas J. Vereecken

- Using an existing network of surveyors familiar with the sites and potentially available to undertake pollinator monitoring;

- Gaining access to a wider knowledge-exchange network including online infrastructure and stakeholders to aid promotion of survey activities.

Here, we focus on three such sampling schemes:

1. The LUCAS[8] network of sampling sites across Europe is already based on a random or stratified random sample; INSPIRE[9] compliant in data standards.

2. The Long-Term Ecosystem Research (LTER)[10]

3. Butterfly transect sites co-ordinated by national schemes in a number of Member States (eBMS)[11]

The European Butterfly Monitoring Scheme partnership is described in section 1.2.2. Here, we provide further details for the LUCAS survey and the related European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL) survey protocol.

5.2.2.1 LUCAS: Land Use and Coverage Area frame Survey

LUCAS was set up as an area-frame survey to derive land cover/land use statistics and transect monitoring, including additional modules (e.g. soil, grassland condition). Eurostat has carried out this survey every 3 years since 2006 to identify changes in the European Union in land use, i.e. the socioeconomic use of land such as agriculture, forestry, recreation or residential use, and land cover, (e.g. grass, broad-leaved forest, or built-up area). The latest LUCAS survey dates from 2018 and provides information from across the EU Member States for more than 330,000 survey points. In each survey round a stratified random selection of >1 million 2 x 2 km grid cells is selected from which a subset of grid cells is selected for field survey. In a grid cell a single point is selected for field survey. At each point a professional surveyor takes a series of measurements, including land use (33 subclasses) and land cover (76 subclasses), environmental information (e.g. irrigation, grazing, burning), photos in 4 directions, in case of grassland a vegetation survey and in 1 out of 10 samples a topsoil sample for laboratory analysis. Single point samples are thus very small and field surveys are rapid and broad scale. There is a limited possibility to have additional modules in the survey. Results from LUCAS are broadly used for EU agricultural and environmental policy and planning. See also Table 5.8.

The LUCAS sampling framework of a regular grid of 2 km squares across the whole of Europe provides an objective, un-biased basis for aligning EU-PoMS sampling. However, the sampling protocols within LUCAS offer relatively limited direct benefit for EU-PoMS. Firstly, EU-PoMS transects would need a larger site (e.g. for pan traps and transects) than the LUCAS points. Second, the added benefit of linking to the LUCAS protocol is limited as each year a different subset of sites is surveyed and relevant information for pollinators is not taken from the survey points. The EU-PoMS would be an annual survey of all sites. Third, each site receives just a very quick visit, during which no pollinator measurements can be taken. Any EU-PoMS activity would have to be set up independently from the LUCAS work, will benefit only very little from LUCAS point information, and will not benefit from LUCAS survey infrastructure. The main benefit of a link to the LUCAS site network is that it provides the grid structure that allows for a stratified random selection of EU-PoMS survey sites. A further benefit is that for the grassland and landscape features, LUCAS modules would provide important contextual information. The LUCAS grassland module was piloted in 2018 with 3000 and with full implementation of 20,000 points in 2022.

5.2.2.2 EMBAL: European Monitoring of Biodiversity in Agricultural Landscapes

The European Monitoring of Biodiversity in Agricultural Landscape (EMBAL) methodology is proposed as a means to assess farmland biodiversity. It has not been applied in practice, but will be piloted in 2020 in a few regions. It is not clear what its status will be in the future. EMBAL proposes a field surveys of plots with a size of 25 ha (500 x 500 m). The survey follows a three-fold approach: (i) an area survey, where parameters on agricultural parcels and landscape elements are recorded; (ii) a vegetation survey based on transect walks, during which parameters of the vegetation and key species are assessed; and, (iii) a photo documentation, which is a useful tool for the visual characterisation of the plot as well as tracking change over time. EMBAL builds on the European LISA study (Landscape Infrastructure and Sustainable Agriculture) and the German High Nature Farmland indicator monitoring.

8 https://esdac.jrc.ec.europa.eu/projects/lucas
9 https://inspire.ec.europa.eu/training/inspire-data-specifications
10 https://www.lter-europe.net
11 https://butterfly-monitoring.net/ebms

Table 5.8. Summary of candidate site networks for the EU Pollinator Monitoring Scheme typically biased towards areas rich in butterflies and/ or accessible to volunteers

Attribute	LUCAS	LTER	eBMS
Countries covered	All EU countries	24 partner countries in LTER-Europe	16 partner schemes in 13 EU Member States
Link	https://esdac.jrc.ec.europa.eu/projects/lucas	https://www.lter-europe.net/lter-europe https://butterfly-monitoring.net/ebms	https://butterfly-monitoring.net/ebms
Lead organisations	EU Commission, with technical support by JRC and Member States	Various organisations co-ordinate in Member States	Various organisations co-ordinate schemes in Member States. eBMS co-ordinated by Butterfly Conservation Europe & UKCEH
Site selection method	Random selection	Non-random selection of sites. Typically sites accessible to universities or research institutes.	Non-random selection of locations. Selected by participants. Typically biased to areas rich in butterflies and/ or accessible to volunteers.
Years running	2009 onwards	LTER-Europe launched in 2003, with some monitoring at sites with longer time-series	Earliest scheme began in 1976 (UK), with further schemes established from 1990 onwards.
Primary data collected	Estimates of land cover. Properties of topsoil	A range of biotic and abiotic factors	Abundance of individual butterfly species throughout the main season of insect activity
Regularity of sampling	A proportion of sites surveyed each year (late spring/early summer and late summer)	Regular sampling within the season for many protocols	Weekly sampling, although gaps due to poor weather or lack of availability of recorders
Total number of squares/ locations	Around 1 million points across the EU as intersection of a 2 km grid	410 sites across the EU	5,839
Access arrangements	Data is freely available via Eurostat	Data available on request from individual LTER sites	Data available under licence via the eBMS partnership
Surveyors and their expertise	Professional survey in the field, supported by photo-interpretation in the office.	Professional scientists following survey protocols for biological sampling (e.g. vegetation) and abiotic measures (e.g. air, water, soil chemical composition; meteorological measurements)	Citizen science with expert volunteers, often trained in the method and butterfly identification.

EMBAL focusses on agricultural parcels and landscape elements in agricultural landscapes. During the survey, land use and land cover is documented in the 500 x 500 m plot and 4 short (20 m) transects are surveyed for key plant species selected to indicate the condition of agricultural areas. The EMBAL method for site selection and surveys is not directly applicable to the EU-PoMS. However, EMBAL will provide an assessment of biodiversity over agricultural areas that can act as a potential explanatory factor to interpret pollinator trends. The Commission is currently piloting EMBAL and aims to implement it in all Member States in coming years.

For the three sampling networks (LUCAS, LTER and eBMS) we summarise their key features (Table 5.8) and assess the coverage of sampling sites in comparison to land cover categories (Tables 5.9–5.11).

5.2.3 Existing site networks for co-location of pollinator surveys

For the three sampling networks considered (LUCAS, LTER, eBMS) we matched each to their land cover coverage (% cover of each class) according to the CORINE Land Cover (CLC) map 2012 (Tables 5.9, 5.10 and 5.11. We summarised the coverage of agricultural (AG), semi-natural (SN), urban (U) areas, on the basis of % cover values from the CLC for categories defined as follows:

- AG = CLC land cover within the Arable and Horticultural or Improved grassland class;
- SN = CLC land cover within forest and semi natural or natural areas or wetlands;
- U = CLS land cover within artificial surfaces.

Note that area of water bodies (inland and marine) was also calculated for completeness, even though they do not support populations of pollinating insects.

Table 5.11. Summary of CORINE Land Cover (CLC2012) classes percent by country, intersecting with locations of European Long Term Environment Research (LTER) sites. * - non-EU countries; na - not available.

Country	Number of sites	Artificial surfaces (U)	Agricultural areas (AG)	Forest and semi natural areas, wetlands (SN)	Water bodies
Austria	36	5.6	11.1	75.0	8.3
Belgium	35	11.4	11.4	77.1	0.0
Bulgaria	5	80.0	20.0	0.0	0.0
Croatia	2	0.0	50.0	50.0	0.0
Cyprus	0	Na	Na	na	na
Czechia	18	16.7	16.7	61.1	5.6
Denmark	2	50.0	0.0	50.0	0.0
Estonia	0	na	na	na	na
Finland	16	6.3	6.3	75.0	12.5
France	60	15.0	30.0	53.3	1.7
Germany	34	11.8	50.0	35.3	2.9
Greece	0	33.3	16.7	50.0	0.0
Hungary	11	0.0	45.5	36.4	18.2
Ireland	0	na	na	na	na
Italy	79	2.5	17.7	51.9	27.8
Latvia	3	0.0	33.3	33.3	33.3
Lithuania	0	na	na	na	Na
Luxembourg	0	na	na	na	Na
Malta	0	0.0	0.0	0.0	0.0
Netherlands	1	100.0	0.0	0.0	0.0
Norway*	22	0.0	40.9	59.1	0.0
Poland	17	11.8	0.0	82.4	5.9
Portugal	11	0.0	36.4	54.5	9.1
Romania	10	0.0	20.0	80.0	0.0
Serbia*	5	20.0	0.0	80.0	0.0
Slovakia	10	10.0	10.0	80.0	0.0
Slovenia	13	7.7	15.4	69.2	7.7
Spain	22	4.5	13.6	81.8	0.0
Sweden	20	10.0	20.0	65.0	5.0
Switzerland*	24	0.0	0.0	100.0	0.0
United Kingdom*	60	5.0	46.7	38.3	10.0
CLC full extent	516	3.3	33.5	41.0	22.2
CLC EU	410	5.0	45.6	46.9	2.6

We recommend aligning the pollinator monitoring with the LUCAS sample grid given its unbiased coverage across Europe (see further details in section 5.2.2). The LTER and eBMS networks are less representative of the overall landscape of Member States. The selection of locations for pollinator monitoring within the large pool of LUCAS grid squares could be achieved through either

Table 5.12. Summary of CORINE Land Cover (CLC 2012) classes by country, intersecting with the LUCAS sample grid. * non-EU countries.

Country/Region	**Number of sample points**	**Artificial surfaces (U)**	**Agricultural areas (AG)**	**Forest and semi natural areas, wetlands (SN)**	**Water bodies**
Austria	20,982	5.4	31.9	61.8	0.9
Belgium	7,673	20.3	57.8	21.2	0.7
Bulgaria	27,731	4.6	51.7	42.8	0.9
Croatia	14,141	3.3	40.5	55.0	1.2
Cyprus	2,313	8.5	47.3	43.9	0.3
Czechia	19,716	6.7	56.7	35.9	0.8
Denmark	10,771	7.5	76.1	15.2	1.2
Estonia	11,322	2.2	31.9	61.3	4.7
Finland	84,316	1.4	8.5	80.5	9.7
France	137,047	5.6	59.5	34.3	0.6
Germany	89,399	9.5	57.1	32.2	1.2
Greece	32,817	3.0	39.4	56.6	1.1
Hungary	23,267	6.2	65.8	26.0	1.9
Ireland	17,399	2.5	68.4	27.3	1.8
Italy	75,034	5.2	52.3	41.6	0.8
Latvia	16,135	2.0	41.2	54.8	2.1
Lithuania	16,234	3.2	59.9	34.9	2.1
Luxembourg	644	9.3	54.3	35.9	0.5
Malta	79	27.8	50.6	20.3	1.3
Netherlands	8,882	15.0	67.7	12.6	4.7
Poland	77,964	5.8	59.5	33.2	1.5
Portugal	22,144	3.7	47.0	48.3	1.0
Romania	59,558	5.3	57.3	35.7	1.7
Slovakia	12,265	5.8	47.3	46.2	0.7
Slovenia	5,064	3.0	34.9	61.6	0.5
Spain	124,543	2.3	47.5	49.5	0.7
Sweden	112,385	1.4	8.8	81.3	8.4
United Kingdom*	61,038	8.4	56.3	34.2	1.0
CLC full extent	1,090,863	3.32	33.46	41.03	22.19
CLC EU	1,029,825	4.95	45.58	46.87	2.59

Table 5.12. Summary of CORINE Land Cover (CLC2012) classes by country, intersecting with Butterfly Monitoring Scheme transects. * non-EU countries.

Country/Region	**Number of sites**	**Artificial surfaces (U)**	**Agricultural areas (AG)**	**Forest and semi natural areas, wetlands (SN)**	**Water bodies**
Belgium	88	12.5	44.3	40.9	2.3
Catalonia	132	4.5	24.2	71.2	0.0

Country/Region	Number of sites	Artificial surfaces (U)	Agricultural areas (AG)	Forest and semi natural areas, wetlands (SN)	Water bodies
Germany	907	23.6	51.3	24.8	0.3
Finland	110	5.5	54.5	39.1	0.9
France	354	14.1	53.1	30.8	2.0
Ireland	277	17.0	51.6	30.7	0.7
Luxembourg	110	2.7	67.3	30.0	0.0
Netherlands	1,583	21.3	30.2	47.3	1.2
Romania	10	0.0	80.0	20.0	0.0
Sweden	421	6.4	45.6	47.0	1.0
Slovenia	42	4.8	64.3	28.6	2.4
UK*	1,805	16.3	39.4	43.0	1.2
CLC full extent	5,839	3.3	33.5	41.0	22.2
CLC EU	4,034	4.95	45.6	46.9	2.6

random or stratified-random selection. For example, to increase coverage of agricultural areas, a weighted-random (Thompson 2012) selection procedure could be deployed. Such weighting would introduce a known bias towards an area with a higher cover of agricultural land which could then be accounted for within assessments of trends for Member States. Similarly, weighted-random selection could be applied for other land cover types of interest to pollinators, such as semi-natural grasslands. For example, if some regions or habitats are disproportionally important for pollinators, then additional sampling in these cases would be beneficial for estimating trends with greater precision. Where disproportional sampling is applied, this bias can be corrected within the analysis of trends.

Some Member States are already implementing pollinator monitoring schemes or plan to do so in the near future. Our MVS should aim to complement these existing activities although it may not be possible in all cases; see full consideration of this in section 5.6.

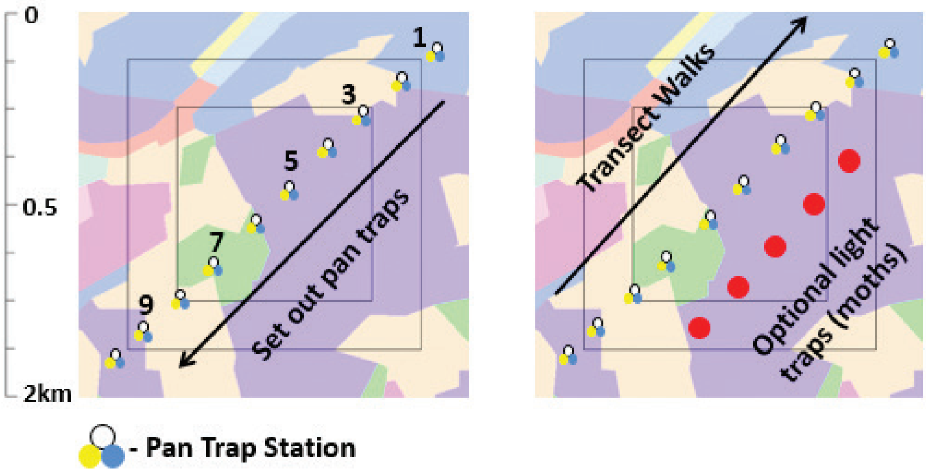
5.2.4 Summary of survey protocol to be implemented in selected 1 km squares

A two-day protocol is recommended, for deploying pan traps for a 24-hour period, and to undertake transect walks during the same period. To adequately cover the flight period of pollinator groups it is recommended that each site is sampled between 6 to 10 occasions per year depending on climatic zones, for instance to accommodate longer activity seasons in warmer parts of Europe. The recommended level of sampling is potentially more intensive than is necessary to provide robust national estimates of pollinator trends. However, it is not possible to refine these estimates without further field testing and we take a precautionary approach of proposing a relatively high level of sampling. We recommend a pilot to test field methods and an evaluation of the costs and benefits (precision of estimate of diversity and abundance) of levels of sampling (see section 9.1).

A volunteer/expert would lay out ten pan traps diagonally across the 2 km grid square to accommodate the 10 pan trap stations. Transect walks would then be undertaken in the opposite direction counting four separate transects, each of 500 m length. Each 500 m section would be divided into ten 50 m sub-sections. The main pollinator groups would be counted separately on 500 m transect sections (i.e. only one group at any time: butterflies, bumble bees, hoverflies and solitary bees) due to each requiring a different 'search image' to reliably estimate abundance. If light traps are included in the protocol, there would be five traps at least 100 m apart set at the end of one day and collected the next. Pan trap and transect samples would be accompanied by a rapid assessment of the floral community to help understand the effects of local resource availability on insect counts.

The design presented here (Figure 5.5) is the recommended ideal approach and has been proposed based on experience of implementing pollinator monitoring within Europe. We recognise that in practice there will be additional constraints on placement and numbers of pan traps and transects, for example due to constraints of land access, e.g. livestock precluding deployment of pan traps. Pilot field testing will identify some of these issues (section 9.1), and full implementation of the EU Pollinator Monitoring Scheme will require a detailed field handbook to support surveyors that would include guidelines on acceptable simplifications.

Figure 5.5. Schematic of the sampling locations of pan traps to be set out for 24 hours per sampling visit across each grid square (e.g. 2 km). Ten sets of 3 standard (350 ml) plastic bowls[12] painted UV-bright yellow, blue and white will be mounted at vegetation height at ten locations across each square and filled with water and a drop of non-scented washing liquid. Transect walks will be conducted in the same area, but at a minimum distance of at least 100 m between transect walks to ensure data independence.



5.2.5 Further considerations for design refinement

We recognise the importance of landscape effects and flower abundance in affecting pollinator counts. The power analysis (section 5.1) conducted to date has been based on sites across landscapes (as far as data was available) and which vary in their characteristics. This variability from existing datasets is quantified in the power analysis (section 5.1) and has influenced the recommended sample size. It is essential that a pollinator monitoring scheme is implemented as a random or stratified-random sample within and across member states. This is required to reflect the variability in EU landscapes, habitats and floral richness - both depauperate and diverse landscapes. As a long-term monitoring scheme, areas currently rich in flowers may not remain so in future and we want to detect effects on overall pollinator abundance of changes in land use. Within the analysis of data from a pollinator monitoring scheme, we envisage that landscape characteristics (e.g. from Sentinel Earth Observation products) would be investigated to assess the importance in determining pollinator abundance and to enable trends to be extrapolated. The use of Earth Observation products have not been evaluated in detail within this report as the options available are likely to

12 The potential for more environmentally sustainable trap designs should be evaluated

develop rapidly over the next few years as more refined land cover products using Sentinel are developed. Any future analysis of pollinator population trends would use the best available explanatory datasets available, and which are likely to change over time. Detailed flower abundance assessment is not included as part of the recommended pollinator sampling methods, but we will seek to align the pollinator monitoring scheme sampling with the EMBAL programme that includes vegetation assessment. In addition, we recommend a rapid assessment of floral resources (e.g. as used by O'Connor et al. 2019) to coincide with sampling for pollinating insects (see sections 5.2.3). For costings we assume the floral assessment would take 20 minutes but a detailed protocol for such assessments has not been defined in this report; options would be tested as part of a pilot phase for implementing a full pollinator survey (see section and 9.1.1).

We recommend that aspects of sampling are further evaluated as part of a pilot phase for a pollinator monitoring scheme, prior to full implementation across the EU. In this report, it has not been possible to fully prescribe all details of a monitoring scheme, for example. We recommend further discussion with Member States as part of the next steps to implement an EU pollinator monitoring scheme (section 9.2).

5.3 Complementary Approaches to the Minimum Viable Scheme

Complementary Approaches (Figure 5.1) comprise two modules of the EU-PoMS, within the Core Scheme (and in addition to the MVS), but which are not yet ready for large-scale adoption as they require some field validation and refinement of methods, in the case of moths (section 5.3.1), or which cannot otherwise be monitored through a large-scale standardised scheme (MVS) but instead require species-specific methods in the case of rare and threatened pollinator species (section 5.3.2).

5.3.1 Moth module

5.3.1.1 The importance of moths

Moths (all Lepidoptera which are not Papilionoidea) are a very large and diverse group, with an estimated 8,026 species in Europe (Karsholt & Razowski 1996) of mostly nocturnal species, though there are also crepuscular and diurnal species. Not that much is known about the relative importance of nocturnal pollination; for some plant species they are known to be strongly dependent on nocturnal pollination (Bertin & Willson, 1980; Fleming et al., 1996; Young, 2002), and theoretical models also suggest nocturnal pollination is of great importance (Miyake & Yahara, 1999), but at the community level the importance of nocturnal pollination remains poorly studied (Hahn & Brühl, 2016). However, the importance of nocturnal pollination in general, and moths in particular, is becoming increasingly clear (VanZandt et al. 2020, Macgregor et al. 2019, Macgregor et al. 2015, Hahn & Brühl 2016; Walton et al. 2020). When only diurnal pollinator networks are examined a large portion of plant-visitor interactions can be missed (Devoto et al., 2011), and moths could be an effective way to monitor nocturnal pollination.

A recent study found that, although moths do not appear to significantly contribute to crop pollination directly, they appear to contribute strongly to non-crop pollination in agricultural landscapes (Hahn & Brühl, 2016). This helps maintain biodiversity in agro-ecosystems, which is considered a valuable ecosystem service (Hahn & Brühl, 2016; Power, 2010; Ricketts et al., 2008).

Moths are also documented as important pollinators of many wild flower species (VanZandt et al. 2020, Macgregor et al. 2019, Macgregor et al. 2015, Hahn & Brühl 2016). Besides pollination, moths have important functional roles in food webs (Singer et al., 2012), as herbivores (Franklin et al., 2003; Bernays et al., 2004) and as bulk food for birds (Sierro et al., 2001) and bats, (Rich & Longcore, 2006; Threlfall et al., 2012).

Due to their short generation times, in combination with their high population densities and high species richness, moths can be used as indicators for environmental change (Rákosy & Schmitt, 2011) as well as for trends in insect biodiversity (Fox, 2013). Moths are also important indicators of the effect of light pollution on nocturnal pollinators (Van Langevelde et al., 2018). Their importance to pollination is therefore both direct (by proving pollination of wild plants) and indirect (by helping to maintain ecosystem resilience).

5.3.1.2 Moths as optional additional module

Though moths are not part of the core monitoring scheme (see section 3.2), there are options for Member States to include them as an additional part of the monitoring scheme. There are established light-trapping methods to monitor moths (section 4.3.5) and in some countries there are groups of interested volunteers. Image recognition for moths is developed in northwest Europe to support identification. As current monitoring techniques are relatively efficient, the inclusion of this large group could be a relatively cost-effective addition; in a completely professional-based monitoring scheme, including moths increases the costs by ~7%, and these costs will be reduced if more volunteers are included (section 5.5.3.4). A standard trap design would be required to standardise this method.

A further potential benefit of including moth monitoring would be to build up species distribution maps for this group and reference libraries to support identification work. Other questions could also be addressed, for example with regards to problems with pest species such as oak or pine processionary caterpillars.

5.3.1.3 Method

The inclusion of a moth module to the MVS would require a relatively modest alteration to the overall scheme. For instance, during the first day of a regular EU-PoMS sampling visit, five LED light traps (4.3.5) would be installed while placing the pan traps, and this is estimated to take ~25 minutes for all the light traps. On the second day, collecting all traps is estimated to take 75 minutes.

Moths are currently not widely monitored, although successful moth monitoring schemes based on light traps have run for several decades in the UK (Conrad et al. 2006) and in Finland (Pöyry et al. 2011) and new initiatives are being initiated in other countries. In the Netherlands, a modular system with a battery powered LED light is becoming increasingly popular to monitor the moths in an agricultural landscape (see Figure 5.7). The main strength of this system is its ease of use. The trap consists of a bucket with a funnel, and an LED mount on top, powered by a power bank. A single trap costs ~€110, and is expected to last at least five years. To deploy a trap, all that is required is placing the trap on the ground and connecting the USB cable of the LED light to the battery pack. A light sensor automatically detects when the LED light should be enabled, so deployment can be done at any time during the day. Setting a trap takes ~5 minutes, which includes walking at least 50 m away from other light sources. We propose deployment of these traps is combined with the placement of the pan traps. The next day, while collecting the pan traps, the light traps could also be collected. The collection is simple, the trap is opened and every captured moth is photographed and then released. In most cases the moths will not be very active, although activity is affected by temperature. A cardboard egg-carton, or similar, is placed in the trap for the moths to hide in. During warm days, it might be necessary to open the trap under a mosquito net or use ethyl acetate to sedate captured moths temporarily. The collection takes ~15 minutes per trap, depending on how many moths are caught. A specially designed App[13] is available to rapidly identify the captured specimens. For most north-western European countries this software is well developed. For many southern and eastern European species the underlying datasets (e.g. picture collections) are currently not large enough to support identification. However, the quickest way to collect these images would be by starting with a monitoring scheme, and have an expert identify pictures initially; once a species has been identified in 50 to 100 images it can generally then be added to the automatic recognition module.

Figure 5.6. Typical modular system with a battery powered LED light to monitor the moths. Photo credit: Jurriën van Deijk.

The additional costs of this module (Appendix 5.3.) depend on the level of involvement of volunteers and varies depending upon distribution of sites. In an eastern European country it would take roughly two hours of extra time for each visit (5 traps x 5 minutes for deployment, 5 traps x 15 minutes collection, and 20 minutes for identifying images). This takes into account that not all moths can currently be identified by image recognition software, and as the software learns to recognise more species this will become more efficient. We propose 8 visits a year, which would require 16 hours per site per year. In north-western European countries additional image analysis time may not be necessary, and only ~13hrs/site/year would be required.

Technological development: The light trap method described here requires the use of automatic identification of the majority of species. This software is currently not capable of recognising all European species. The costs of developing it further will require a bespoke study in each region. Note that automatic recognition is not required to start such a scheme, as the most important limiting factor is image availability. It is likely such software will be developed alongside a monitoring scheme. Some taxa will not be identifiable by image recognition and dissection would be required for identification to species.

13 https://play.google.com/store/apps/details?id=org.observation.obsidentify&hl=nl

5.3.2 Rare and threatened species module

The standardised monitoring protocols proposed (section 5.2.3) are suitable for obtaining general data on European, as well as national, trends in the abundance or species richness of pollinating insects. However, many insect species have exceptionally small geographic ranges, and for instance may occur only on a single island or mountain. Simply increasing the sampling effort of standardised monitoring approaches is not sufficient to provide reliable data on the population trends of these rare species, as these schemes are designed to be representative of the landscape (not the taxon), and therefore unavoidably biased towards more common and widespread species. Therefore, the current proposal will inevitably under-represent rare species (which are usually also the most threatened). However, these species often represent national and European endemics (section 3.1) for which the European Union has a high responsibility, but about which little is known despite their important contribution to biodiversity and ecosystem health in Europe. The chronic lack of data on distribution, population trends, ecology and threats to insect species is indeed a major obstacle to assessing their conservation status and to monitoring overall biodiversity trends. This is illustrated by the European Red List of Bees (Nieto et al. 2014), where 56% of the bee species occurring in the EU were found to be Data Deficient and where their population trend was classified as "unknown" for 79% of the species. These numbers emphasise the strong need for more targeted research into the population trends of pollinator species, particularly those of rare and threatened species, which has consequently been proposed for 89% of the wild bee species on the European Red List (Nieto et al. 2014).

The IUCN (International Union for Conservation of Nature[14]) Red List of Threatened Species™ is the most important tool providing information on the conservation status of species and can be considered a "barometer of life" (Stuart et al. 2010). It provides valuable data for measuring progress towards international biodiversity targets, such as the Convention on Biodiversity (e.g. Aichi Target 12[15]) and the Sustainable Development Goals[16] (e.g. SDGs 14 and 15). While standardised monitoring approaches will help to close knowledge gaps in common and widespread species, it is crucial to tailor specific surveys to obtain information on rare and threatened species and thereby prevent 'silent' extinctions and successfully reach internationally agreed biodiversity targets. Contrary to the standardised monitoring scheme, such targeted monitoring requires the application of specific methods to obtain high quality data on population trends of threatened species (e.g. using pheromones for certain moth species). Therefore, it is recommended to establish a complementary module within the EU pollinator monitoring programme that focuses on improving data availability for rare and threatened species by conducting targeted field work for them. It will neither be possible nor necessary to monitor all rare and threatened species every year and in every region, but it is recommended to record the distribution, population size and threats in intervals that are short enough to inform Red List assessments (i.e. less than 10 years) and cover a large number of species. The monitoring interval should be adapted based upon clear prioritisation rules, with shorter monitoring intervals recommended for species with higher extinction risk and longer monitoring intervals for species with lower extinction risk.

It is proposed to provide funding additional to the EU Pollinator Monitoring Scheme that would allow monitoring of 50 to 100 rare and/or threatened species each year (so that up 500 to 1,000 species can be surveyed in a decade). This targeted monitoring should focus not only on rare and/or threatened species from the taxonomic groups already covered by the standardised scheme (butterflies, bees, hoverflies, moths), but could also include other insect species and even non-pollinators. Priority should be given to species with the highest extinction risk (i.e. Critically Endangered) and species assessed as Data Deficient, followed by Endangered and Vulnerable species, in order to obtain high quality data for measuring success of conservation action and progress towards internationally agreed conservation targets. Least Concern or Not Evaluated species with small geographic ranges (i.e. extent of occurrence <5,000 km² as defined by the IUCN Red List criteria) could also be included. As most threatened species have a small geographic range and a short phenology, such targeted monitoring does not require large additional funds, for example €5,000 to €20,000 per species).

Such a rare and/or threatened-oriented monitoring approach will have to utilise the most suitable species-specific field methods available for each species and site, including many of those reviewed in Section 4). The method chosen should be equipped to provide the following information:

- *Distribution*: Distribution data are the most basic and fundamental data for biodiversity conservation. They are not only crucial for Red List assessments (IUCN Red List criteria B and D2), but also for identifying Key Biodiversity Areas (KBAs)[17] or other areas important for biodiversity, to inform strategic conservation planning and to implement appropriate conservation action. However, distribution information is usually incomplete or outdated for insects. Therefore, collecting up-to-date distribution data has the highest priority in the targeted monitoring for rare and threatened species. For species with a lack of recent records, targeted searches should be conducted based upon the records available in the literature, museum material and databases to reconfirm their presence. For species with presumably incomplete

14 https://www.iucn.org
15 https://www.cbd.int/aichi-targets/target/12
16 https://sustainabledevelopment.un.org/?menu=1300
17 http://www.keybiodiversityareas.org/home

distribution data, the known occurrences as well as similar habitats in the vicinity of known records (or based upon species distribution modelling) should be surveyed so that the most comprehensive and up-to-date distribution data possible is obtained. For species that are easy to identify, citizen science approaches may be applied, while for elusive species the use of modern methods (e.g. eDNA, detection dogs) may be prioritised. Spatial data needs to be made available with open access (e.g. via online platforms such as national systems and Observation.org[18]) to facilitate conservation practice (i.e. Red List assessors, national and regional authorities, NGOs, Protected Area managers) and encourage cross-sectoral collaboration, which is critical for successful conservation practice.

- *Population*: Population data is crucial to assess the extinction risk of species (IUCN Red List criteria A, C and D), identify populations with high conservation value and instigate conservation action timely. Estimating population trends is, therefore, a key element of species monitoring. To obtain data on population trends of rare and threatened species, it is important to use a standardised (but species-specific) method over time to measure or estimate population sizes or abundances. Methods to record population sizes depend on several factors (detectability, habitat, phenology, life cycle, daily activity pattern) and, therefore, can vary strongly among species. They may include standardised trapping/recording or more sophisticated methods, such as mark-recapture (for species with small populations). Each survey aims to acquire robust data, allowing us to estimate or infer population trends of the respective species at a given site.

- *Ecology*: Information on the habitat preferences of rare and/or threatened species is crucial for identifying and assessing the effects of potential threats (like habitat loss and fragmentation), and improving conservation planning and habitat management. Therefore, habitat variables considered relevant for the respective species should be recorded during each survey. These data will also help to improve future targeted searches for this species and improve distribution data (see *Distribution* above). Important habitat parameters to consider are, for example, host plant, vegetation structure, nesting sites, microclimate, soil parameters etc. (depending upon the species under study). Habitat data will have to be stored alongside distribution and population data in an online, open access database so that this information can be used to inform Red List assessments and conservation action.

- *Threats*: Halting biodiversity decline is only possible by mitigating threats to species. While some general information on threats to European biodiversity is available, conservation action requires much more specific information on the major threats to each species at a given location. Therefore, actual or potential threats to the species under study should be re-

18 https://observation.org


Pieris cheiranthi, Axel Hochkirch

corded at each site. These may include details on known threats such as agricultural practices (e.g. type and density of livestock, crop type, use of pesticides and fertilizers, date and type of mowing, ploughing, rolling, drainage, irrigation), forestry (e.g. type, age and structure of forest, dominating tree species, use of liming, pesticides and fertilizers, type and number of roads and logging trails, use of heavy machines and other management practices), land abandonment, urbanisation and infrastructure, aquaculture, wildfires, drainage, damming, canalisation of lotic waters, mining, invasive species, biological resource use, human disturbance, pollution or effects of climate change. A clear scoring system of the severity of each threat, like the one offered by the IUCN Red List, should be applied so that the most pressing drivers of biodiversity decline can be addressed. This information will be critical to improve habitat management and facilitate conservation action.

5.4 Additional, optional, modules to the Core Scheme

These are three modules of the EU-PoMS which are in addition to the Core Scheme (Figure 5.1) and can provide important measures of pollination services (section 5.4.1), flower visitors (section 5.4.2), and wider flying insect biodiversity (section 5.4.3), if MS choose to implement them. All three require substantial methodological development before they can be adopted as standardised methods as part of EU-PoMS.

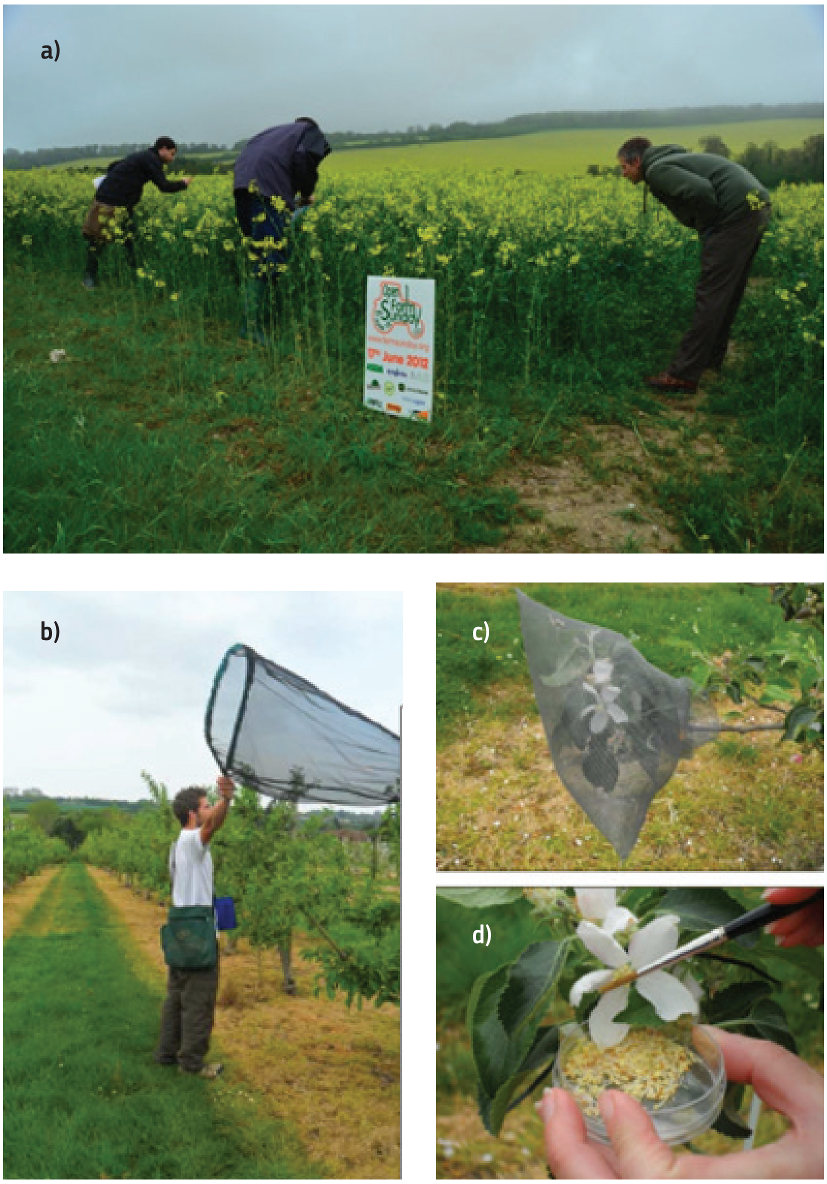
5.4.1 Pollination services

The aim of this module is to generate data on pollination services to insect pollinator-dependent crops, and potentially also to wild flowers. The proposed MVS would allow indirect inference to changes in pollination service through measuring the status and trends of insects known to currently pollinate crops across Europe, or predicted as potential pollinators under future scenarios of environmental change. However, there are a number of additional options for more targeted monitoring of these insect taxa and for direct measurement of the pollination service to crops.

5.4.1.1 Taxa surveyed

This module would involve a focus on either or both of the following: (i) key pollinating insect taxa and species (dependent on crop types and pollinator dependencies in the relevant country, Kleijn et al. 2015) that may already be sampled within the proposed MVS via transect walks or pan trapping, but that could also be more specifically targeted through crop surveys; and (ii) direct measures of pollination to detect changes in pollination service or identify possible deficits (ideally such that these meas-

Figure 5.7. Methods for sampling key crop pollinators a) timed crop watches; b) transect walks in flowering crop fields; and c) direct measures of bagging and d) hand pollination (photo credits: Mike Garratt).



ures are independent of agronomic or regional variation). Detailed information on the key species performing pollination services to different crops across Europe is currently lacking. Existing data comes from a biased set of Member States and crop types.

5.4.1.2 Method for assessing pollination services

Understanding more about changes in pollination services to crops across Europe could involve one or more of the following five methods, listed in order of likely additional effort and cost above the currently proposed MVS:

- *Analysis of known crop pollinators from pan traps or transect walks* undertaken as part of the MVS within 2 km squares. Targeting taxa known to be important crop pollinators at the European (e.g. Kleijn et al. 2015) at the Member State level would provide an indirect assessment of the availability of pollination service providing taxa, but additional supporting research would be needed to extend knowledge beyond bees (section 9.1.2). From pilot studies conducted on oilseed rape crops in the UK, it was found that pollinators sampled in pan traps were not highly representative of those recorded visiting coincident flowering crops on transects within the same 1 km survey square (Carvell et al., 2020). However, pan traps deployed across a stratified sample of 1 km squares were shown to sample known key crop pollinator species through the season, and these can be related to national maps of known crop distribution to make predictions on likely pollination shortfalls (Woodcock et al. 2014). More direct measures within flowering crops may be necessary to more directly sample the active crop pollinating insect community.

- *Timed crop watches*, potentially using the FIT Count approach (Figure 5.6a; section 5.4.2) that may require modification to suit high density crop flowers within fields. These could be implemented during or after the transects conducted as part of each MVS survey, or alternatively as a citizen science activity engaging growers and agronomists in specific crop growing regions (Garratt et al., 2019).

- *Transect walks in flowering crop fields* to monitor changes in crop pollinator activity (Figure 5.6a b), generating counts of flower visitors by broad groups (if purely observational) or to species level (where netting and identification of individuals is possible). Additional crop watches or transects could be targeted to crop fields within the stratified sample of MVS squares; using maps of known crop distribution within these would provide a useful tool to target this approach to monitoring (e.g. in the UK, the UKCEH Land Cover plus Crop maps[19]). Such surveys would add directly to the existing MVS protocols, but only during the bloom period of the target crops.

- *Hand pollination and bagging experiments to measure changes in pollination service* or identify possible deficits (Figure 5.6c and 5.6d; section 6.1.3.2). Typically this would involve tagging crop stems or branches (apples), assigning one set to an 'open' treatment with no experimental manipulation, one as a 'closed' treatment with a mesh bag placed over the crop flowers to exclude insect pollinators, and one as a 'supplementary pollinated' where recorders would collect pollen from neighbouring plants and apply the pollen to open flowers with a paint brush, recording how many flowers were supplementary pollinated (Garratt et al., 2019). This approach would require follow-up visits to then collect and assess seed and/or fruit set from sampled plants, as well as, potentially, at the final crop harvest to assess yield and possibly also quality. As with transect walks, the sampling could be targeted within the MVS square sample using maps of known crop distributions across Europe.

- *Pollination of wild flowers using insect visitors as an indirect measure* of visitation to wild flowers growing within the MVS sample squares. This could build on the FIT Count approach outlined in 5.3.2 and potentially include a behavioural component based on whether insects are actively collecting nectar, pollen or making stigmal contact on flowers. More direct measures of pollination services, using methods equivalent to bagging and hand pollinating crop plants, could also be developed but there are major challenges around the standardisation of such approaches.

5.4.1.3 Additional support or capacity needed to implement pollination service surveys

A better understanding of the relationship between pollinator activity, pollination service levels and crop yield for different crops is required before estimates of changing crop production, linked to insect pollination, can be made based on detecting changes in pollinator activity or crop pollination alone. Based on findings from the UK, the use of simple measures such as seed set show potential for some crops but require further development and testing (Carvell et al., 2016, section 9.1.2).

National-level maps of key crops would be needed for targeting of sampling sites. Although these are not currently available for many Member States, they are likely to be produced in the near future. An example of how these maps could be utilised is the very first UK Crop map (UKCEH Land Cover® plus) which has published information on annual crop types for every field in Great Britain for 2015 (partial GB coverage), 2016, 2017, 2018 and 2019. They exploit openly available satellite data (Copernicus Sentinel-1 C-band SAR, Synthetic Aperture Radar) and, from 2016 onwards, Sentinel-2 optical data, and so are feasible to be produced for the whole of Europe on an annual basis. Where these maps are available, sites additional to the core MVS network could be selected to be representative of the areas of pollinator dependent flowering crops, and potentially weighted towards those of the highest economic value (e.g. soft fruits) or towards those already known to be at risk of pollination deficits. However, crop rotations may necessitate a flexible sampling design given that pollinator-dependent crops may not be grown in the same field in successive years.

There are also several additional requirements adding this module to the MVS, in terms of equipment and training. For instance, bagging experiments to directly test pollination require net bags and specific skills (e.g. training in hand-pollination techniques), with some crops needing specific adaptation of the methodologies due to their individual growth form and fruit/pod/seed development (Garratt et al. 2014a, 2014b). Given the specialist technical skills and knowledge needed for some crop pollination protocols it is likely that professional surveyors would be required, especially if direct measures of pollination services are being employed (Garratt et al. 2019).

5.4.1.4 Pilot work required to develop into a full scheme

For a pollination services module to be implemented alongside the MVS, there are a number of areas where pilot work and methodological development are needed. First, various indirect methods of assessing pollination should be tested against direct measures to validate and calibrate them in a range of crops and countries. This will inform on which method(s) should be taken forward in the final design of this module. Secondly, the degree of replication, spatially and temporally, needs to be tested using further power analyses of existing data and through piloting methods in the field. Based on this, standardised protocols for

19 https://www.ceh.ac.uk/services/ceh-land-cover-plus-crops-2015

specific crop types (e.g. orchard, soft fruit, field crops) could be developed. Thirdly, the additional training required to implement the methods should be assessed and ways to build this capacity in the professional and/or volunteer communities participating in the monitoring scheme developed. An assessment of the costs (equipment, staff, travel etc.) should be undertaken, and take into account the fact that some methods (e.g. bagging of flowers) require surveyors to revisit sampling sites to record the development of fruit/pods/seeds. Finally, standardised methods are currently lacking for assessing pollination of wildflowers, and due to their high species richness and diversity of growth forms and pollination modes, substantial basic research would be necessary to develop an approach to systematically monitor pollination of this group. Further details of pilot work required are given in section 9.1.2.

5.4.2 Flower visitation

5.4.2.1 Flower visitation and plant-pollinator interactions

The aim of this module is to generate data on flower visitation and plant-pollinator interactions that would not be gathered using the core methods currently proposed as part of the Minimum Viable Scheme. Our key recommendation is for a timed (10-minute) count of insects visiting flowers recorded to group level that has already been implemented as a citizen science initiative in the UK[20], Ireland[21] and Cyprus[22], with benefits extending to public engagement, awareness and capacity building. This approach is being further explored in South America as part of an ongoing collaborative project[23] and also aligns with the approach of the Wild Pollinator Count in Australia[24].

Since the ecosystem function of pollination depends upon the ecological interactions between insects and flowers, it is important for any long-term pollinator monitoring scheme to consider how these interactions may change over time and space, in addition to monitoring the pollinators. The MVS methods (pan traps and transect counts, section 5.2.3) will not collect any plant-insect interaction data directly. Data on plant-pollinator interactions have been used to answer many key questions in ecology, relating to, for example, the impacts of different stressors such as climate change, invasive plant species (Stout & Tiedeken, 2017) and urbanisation (Buchholz and Kowarik, 2019), or the effects of habitat restoration (Kaiser-Bunbury et al, 2017) on ecological networks. Ecological networks and their visualisation can also be used to support public engagement and to enhance the value of citizen science, in which people actively contribute to scientific research (Pocock et al, 2016).

5.4.2.2 Taxa surveyed

This module would cover all flower-visiting taxa and would therefore include groups not already targeted under the MVS. Taxonomic groups would need to be adapted for some EU countries, but in the UK and Ireland ten categories are currently used at the insect group level: honey bees, bumble bees, solitary bees, wasps (including ichneumon wasps), hoverflies, other flies, butterflies and moths, beetles (larger than 3 mm), small insects (such as pollen beetles) less than 3 mm long, and all other insects. In both schemes, 14 focal plant species are identified[25], and volunteers are encouraged to observe these species, although they can also observe any other flower that is attracting insects; the target flower list would need to be adapted and tailored for each Member State, aiming for overlap between lists to enable comparisons of visitation across regions.

5.4.2.3 Method for flower visitation recording: Flower-Insect Timed counts (FIT Counts)

Flower-Insect Timed counts (FIT Counts) of 10 minutes, recording insects to group level with some photographic verification of groups and target flowers, have been adopted within the UK Pollinator Monitoring Scheme (PoMS, see section 1.2.4) and are the method evaluated in section 4.2.1. There are two alternative methods for collecting flower visitation data that could be employed in the context of EU-wide monitoring:

- *Recording flowers visited on EU-PoMS transects* (for butterflies, bumble bees, hoverflies and solitary bees) conducted as part of the MVS. Insects seen on flowers within each 500 m transect section (as opposed to those in flight or resting, see section 5.2) would be recorded to species level where possible and to taxonomic group level as a minimum, with the species of flower being visited. A photograph could be used to document the flower-insect interaction, provided this did not interfere with the recorder observing other insects on the transect. Modification of the transect recording form would likely be required, but without any significant additional effort on the part of the surveyor; however, this addition could present a significant additional effort requirement and training of (volunteer) recorders.

20 https://www.ceh.ac.uk/pollinator-monitoring
21 https://pollinators.ie/record-pollinators/fit-coun
22 https://www.ris-ky.eu/poms-ky
23 https://bee-surpass.org
24 https://wildpollinatorcount.com/2020
25 https://www.ceh.ac.uk/sites/default/files/FIT%20Count%20survey%20guidance%20v4.pd


Gasteruption jaculator, Axel Hochkirch


Bombus lapidarius & *Eristalis intricarius*, Michael O'Donnell

Lauxiniidae, Axel Hochkirch

- *Photographic verification of insect flower visitors* to morphospecies level during a fixed time period: the Spipoll[26] approach. Spipoll is a citizen science-based monitoring scheme of plant–pollinator interactions across France. Participants take pictures of every different insect visiting the flowers of a freely chosen plant over a specific time (at least 20 min). They then identify each insect photographed to the level of a morphospecies, according to a reference classification of 630 animal taxa via a specifically designed computer aided identification tool[27]. The proposed morphospecies vary in their taxonomic resolutions since most French flower visitors cannot be identified at the species level from photos. Photographs of the plant and its flower visitors are uploaded to the project website along with the time and location of the sampling. Since 2010, more than 16,050 plant-insect interactions have been sampled by 1,037 observers, representing a sampling effort of 9,306 observation hours (Pocock et al, 2016). These data can, with appropriate statistical methods, be used to investigate the response of flower-visitor richness, and to some extent composition, to environmental variables (Deguines et al., 2012). Spipoll has been highly effective in engaging the public; however, the location and timing of samples are non-standardised, and morphospecies level data make it near impossible to develop meaningful measures trends in pollinators.

- The implementation of these two approaches as a module to the MVS is not considered further here, but these could be explored as complementary initiatives to engage citizen scientists more widely.

5.4.2.4 Linking into the Minimum Viable Scheme (MVS)

FIT Counts could be incorporated to the MVS via either or both of the following routes:

- *Replicated FIT Counts on 50 x 50 cm flower patches contained within the stratified site network* of grid squares (2 km for the MVS). These can be located within a square according to the flowering and abundance of suitable target flowers on a given survey date (i.e. they do not need to be fixed locations over time). In the UK PoMS, a minimum of two FIT Counts is carried out per survey visit during which pan traps are deployed across a 1 km square, with typical counts reaching 10 to 14 insects per 10 minutes. Given sufficient surveyor expertise, these could involve recording to higher taxonomic levels than to insect group level.

26 www.spipoll.org
27 spipoll.snv.jussieu.fr/mkey/mkey-spipoll.html

Leptura maculata, Axel Hochkirch

- *Ad-hoc counts by volunteer citizen scientists* across a variety of agricultural, natural and urban habitats using target flowers lists for each country. These could generate a much larger dataset that could be calibrated against core counts from the main MVS site network, and public engagement benefits. In the UK and Ireland, FIT Counts are promoted by a variety of partner NGOs among different wildlife enthusiasts as well as via social media to the general public. FIT Counts could potentially be incorporated within existing Butterfly Monitoring Scheme transects. In Cyprus, promotion is through a network of Environmental Education Centres and strong links with schools. Collated in this way, FIT Count data could be subject to spatial and temporal bias (but see benefits already arising from the Spipoll initiative; Deguines et al., 2012). They would require significant extra support infrastructure to deliver (section 5.4.2.5).

5.4.2.5 Additional support or capacity needed to implement FIT Counts

Whilst the use of volunteers and non-lethal approach typically used to collect FIT Count data are highly cost-effective, there are a number of infrastructure requirements to support their integration as an additional module to the EU-PoMS. Here we list these along with time estimates (days per country) for either set-up/development or ongoing support, based on experience from the UK, Ireland and Cyprus:

- Coordinator time to consult on and specify the list of 10 to 14 target flowers (adapted for each Member State) and insect groups to record, of which the core must include the three bee groups, hoverflies, other flies, butterflies and moths. Estimated to be 10 to 20 days plus expert consultation.

- Design survey materials and resources based on UK PoMS (and Ireland) templates where useful. This could include a guidance and protocol documents, recording forms, insect guides, flower guides and video guides. Estimated to be 20 days, plus sourcing of photographs or video clips; examples are available from the UK[28], Ireland[29] and Cyprus[30]. Translation and production of materials in English and host language. Estimated to be 5 days per language.

28 https://www.ceh.ac.uk/pollinator-monitoring ; https://www.youtube.com/watch?v=IuTiPEJI8rQ; https://www.ceh.ac.uk/sites/default/files/FIT%20Count%20survey%20form%20v4.pdf; https://www.youtube.com/watch?v=1Fm1KKiUC8Q&feature=youtu.be

29 https://pollinators.ie/record-pollinators/fit-count/; https://records.biodiversityireland.ie/record/fit-count; https://pollinators.ie/record-pollinators/fit-count-progress/; https://www.youtube.com/watch?v=MHCp4uP5C8U

30 https://www.ris-ky.eu/sites/www.ris-ky.eu/files/users/PoMS-Ky%20FIT%20Count%20flower%20guide.pdf; https://www.ris-ky.eu/sites/www.ris-ky.eu/files/inline-files/PoMS-Ky%20FIT%20Count%20survey%20guidance%20v2_3.pdf

- Development and hosting of software to capture data online, including photographs, and store securely. Estimated to be 5 days to set up followed by 5 days ongoing support per year, depending on integration potential with existing platforms such as Indicia[31] which is suited to structured biodiversity collection and used for the UK Pollinator Monitoring Scheme.

- Training of local co-ordinators (including use of materials above). Estimated to be 10 days per year.

- Potential App for data capture in the field, although this is not yet operational in UK, potential integration with the App[32] used within the European Butterfly Monitoring Scheme or others. Costs estimated to 50,000 to 100,000 Euros for App development EU-wide; with 20 days ongoing support per year (per country).

- Expert time for verification of flower and insect photos (typically in the UK photos are uploaded from ~50% of all counts submitted; of these in 2018, 87% of insect photos were identified to the correct group and 97% of flower species photos were correctly identified by the volunteer recorder, Carvell et al *pers comm*). Estimated to be 10 to 20 days per year for ongoing verification depending on total number of counts submitted, and an average of 30 seconds to review each record (Breeze et al, 2020). It is recommended that image classifiers are developed to support identification.

- Additional engagement and promotion (above that for EU-PoMS) of FIT Counts via websites and social media channels. Estimated to be 20 days per year.

5.4.2.6 Pilot work required to develop into a full scheme

We recommend a pilot test (see section 9.1.4) with members of the local community to both test the survey with volunteers (e.g. refining the list of target flowers and insect groups to include) and confirm costings and elements of the protocol to be suitable for that particular country (e.g. whether a 10-minute period is optimal in terms of data generated and experience for the recorder; Carvell et al., 2016). Feedback should be gathered from participants in any pilot test, and any necessary ethical approval sought for such an approach where necessary. We recommend that more detailed costings are developed prior to implementation, to the level undertaken for the core components of the MVS.

5.4.3 Wider flying insect biodiversity

5.4.3.1 Taxa surveyed and methods

The effectiveness of insect monitoring greatly depends upon the chosen method(s). All monitoring techniques have biases, and understanding this bias is crucial to interpreting the results of a monitoring programme. In chapter 4, we present an overview of different types of traps and their advantages and disadvantages; in many cases, the extent to which such a bias affects the resulting data is unknown. Our overall assessment of methods concluded that for an EU pollinator monitoring scheme, focussing on our target taxa (bees, butterflies and hoverflies), the use of pan traps in combination with transect walks was the best option (see section 4.6 for detailed rationale).

There is mounting evidence of widespread decline in the insect population and the need for comprehensive monitoring (Outhwaite et al., 2020; van Klink et al., 2020). This requirement encompasses many other taxa beyond those included in our MVS, and so to assess a broad taxonomic range of flying insects we propose an additional module using Malaise traps as the primary method. Malaise traps are not currently suitable for the MVS, partially because these require professionals to set up and maintain them; they are relatively expensive to purchase compared to other methods, and they yield very large samples of which only a small proportion are pollinators, and the identification of bulk samples requires substantial resources (section 4.3.4). The capture of a large number of individuals throughout a flight season does, however, lend Malaise traps as potentially useful for surveying wider (flying) insect biodiversity and they have been successfully used to assess changes in insect biomass (e.g. Hallman et al. 2017). It should be noted that Malaise trapping is not an effective tool for comprehensive monitoring of rare species, but it can be used in certain circumstances. The trapping chance with Malaise traps is relatively low, and its effectiveness strongly depends on species specific traits (see section 5.3.2).

Data from pollinator transect walks and pan traps of the MVS could also be compared with data form Malaise traps if these methods were run in parallel, which allows for additional analyses of the biases of all three methods (section 9.1.5).

31 https://indicia-docs.readthedocs.io/en/latest/
32 https://butterfly-monitoring.net/ebms-app

5.4.3.2 Pilot work required and linking Malaise trapping to the MVS

Malaise traps comprise a wide variety of designs and lack standardisation in terms of implementation and application in the field, which means the results of different trapping schemes are often not comparable, or only comparable with major restrictions. Therefore, a development phase would be beneficial to standardise the design, deployment, sampling regime and sample identification process (section 9.1.5).

Some countries, such as Germany, have established Malaise trapping schemes with a fixed protocol that addresses some of the above challenges. The German Entomological Society Krefeld has been running traps to survey flying insects for over thirty years using a standardised protocol. There are currently over 100 Malaise traps deployed and they capture huge numbers of insects annually; however extending this further is limited by the current capacity of qualified entomologists, although metabarcoding is increasingly used to analyse the captured specimens. As a step towards developing a wider insect biodiversity module connected to the MVS, we propose linking the Malaise trapping scheme in Germany (and potentially other countries) to the MVS by deploying pan traps and transect walks in close proximity to existing Malaise trapping sites. It is important to note that these methods operate on a different time scale, a pan trap + transect visit can be done in 24 hours whereas malaise traps have to be left out for much longer. This would provide additional insights into the potential biases of all three methods and provide an understanding of how well the data from each trap type represents the different groups of insect (see section 4.6.2).

In parallel, further development of high volume, cost effective and high accuracy identification of bulk samples caught in Malaise traps, is also needed in order to be able to up-scale this method for monitoring wider insect biodiversity (sections 8.6 and 8.7).

5.5 Costing of the scheme and options

This section evaluates the costs of running an EU scale pollinator monitoring scheme using a range of different structures; and guidelines on using the EU-PoMS 'Cost Calculator' which has been developed to support costings for the EU-PoMS. The scheme costs considered include the: (i) material costs of equipment and consumables required to implement the different monitoring methods; (ii) the costs of professional field, administrative and identification staff; (iii) additional consumables such as fuel and postage; and, (iv) the costs of training staff and volunteers. Other costs for which data are not available are rolled into administrative and overhead costs (5.5.4.2).

These costs are presented in detail with rationales associated with each, but are also extrapolated upwards to present estimates of the costs of running an EU-wide scheme. This upward extrapolation takes account of differences in costs (particularly staff costs) between countries to give an accurate reflection of the scale of costs required to run a scheme in each country. Although every effort has been made to capture details and variations between countries, in many cases it has been necessary to make assumptions about missing or incomplete data.

Eucera algira, Nicolas J. Vereecken

In order to cover the broad range of potential scheme structures, the project team developed a MS Excel based cost calculator that allows for various scheme designs to be costed. This includes the annual costs of maintaining the scheme and additional upfront costs for schemes when they are first deployed. These costs are projected across a number of site distribution models to highlight the effect that such strategies can have upon the relative costs of running a monitoring scheme at a country and European scale. Instructions on its use are included in Appendix 5.3.

5.5.1 Costing out different methodologies

This section outlines the different methodologies recommended for use in an EU monitoring scheme. We recommend a combination of pan traps and transects, in close proximity (section 4.6). Below we describe the material costs and time (in hours) required to undertake a sampling at a single site per year, when each is visited 8 times a year. We also highlight the costs which need to be incurred on a 5 or 10-year basis. All material costs are derived from the experience of the project team in undertaking and demonstrating these methods and are based on process in the UK and Netherlands. Costs may vary in other countries.

5.5.1.1 Pan trapping

Pan traps are placed in fixed locations, pre-determined by an expert (who places them systematically within a 2 km grid square to minimise bias). Traps are deployed by placing three pans (UV reflective yellow, white and blue) supported on a wooden post (the pan stand in Table 5.13) at ten 'stations' in each site, filled with a water/soap solution (soap to break the surface tension). We estimate placing a single trap (including walking to the trapping location) and describing the location (and local floral community) of the pan trap takes approximately 20 minutes (or 0.33hrs). The time required to walk to and between pan trap stations

Table 5.13. Material costs for undertaking pan trapping

Component	Price (€/unit)	Units required	Expected lifetime	Costs (€/year)
Pans	€ 0.35	30	5 years	€ 2.10
Pan stand	€ 6.28	10	5 years	€ 12.56
Forceps	€ 1.30	1	5 years	€ 0.26
Sieve	€ 3.00	1	5 years	€ 0.60
Mallet	€ 4.00	1	10 years	€ 0.40
Washing liquid	€ 8.80	1	10 years	€ 0.88
Sampling tubes	€ 0.35	10	1 visit	€ 28.16
Ethanol	€ 1.82	1	1 visit	€ 14.56
Muslin	€ 2.50	1	1 visit	€ 20.00
Average Costs/year				**€ 79.52**
Total annual consumable costs				€ 62.72
Additional costs/5 years				€ 10.93
Additional costs/10 years				€ 12.80

Table 5.14. Time (hrs) required to undertake pan trapping; *site set-up includes manual selection and mapping of sites, any initial labour required to prepare the ground for planting pan traps etc.

Task	Time (h/unit)	Units required	Frequency	Total hours/year
Trap placement and floral survey	0.34	10	every visit	3.4
Sample collection	0.25	10	every visit	2.5
Set Up*	0.50	10	10 years	0.5 (average)
Total hours/visit				5.8
Total hours/site/year				**46.7**
Additional time/10 years				5.0

may be extremely variable depending on landscape characteristics, therefore these estimates of time required will likely need refinement during the pilot phase. After 24 hours pan traps are recovered in the same order in which they have been placed out, samples are collected and shipped to be processed and identified by a taxonomist. See Tables 5.13 and 5.14.

5.5.1.2 Transect walk

Each transect is a fixed route with 10 sections of 50 m each. Four separate 500 m transects are set up within a 2 km grid square, with each sampling a separate taxon group: butterflies, bumble bees, solitary bees, and hoverflies. Walking a transect on average takes ~45 minutes. As the pan traps have to be placed, and collected the next day, we propose to walk all transects twice, on separate days. Each year, both transects are described in detail by noting the local attributes such as surrounding habitats, changes in management in the area etc. This takes about an hour per transect. There are two ways a transect can be surveyed, non-lethal sample where species are identified in flight, either to species level if possible, or to group level otherwise. Species can still be caught to aid identification, but are released after capture. Alternatively, anything that cannot be identified is caught and either directly identified or sent to a taxonomic expert for identification (i.e. partial lethal sampling). The non-lethal method is more suitable when working with volunteers, but will take longer to produce high quality data (as volunteers have to gain enough experience to identify most species directly), particularly as many species are cryptic and require identification via traits not easily viable to the naked eye. We list the cost of a single visit using both methods, but for the rest of the calculation we assume partial lethal sampling. See Tables 5.15 and 5.16.

Table 5.15. Material costs for undertaking transect walks

Component	**Price (€/unit)**	**Units required**	**Expected lifetime**	**Costs (€/year)**
Net	€ 15.75	1	5 years	€ 3.15
Sampling tubes	€ 0.70	4	1 visit	€ 22.40
Ethanol	€ 0.23	4	1 visit	€ 7.36
Average Costs/year				**€ 32.91**
Average costs/year (non-lethal)-				€3.15
Total annual consumable costs (lethal)				€ 29.76
Additional costs/5 years				€ 15.75

Table 5.16. Time (hrs) required to undertake transect walks; *site set-up includes manual selection and mapping of sites, taking start and end positions of transects etc.

Task	**Time (h/unit)**	**Units required**	**Frequency**	**Total hours/year**
Walk transect	0.75	4	every visit	24
Describe transect	1.00	2	yearly	2
Set up*	2	1	10 years	0.2
Total hours/visit				3
Total hours/site/year				**26**
Additional time/10 years				2

5.5.1.3 Light traps

Lights traps are placed along the route between the pan traps (keeping a minimum distance of 50 m from the pan traps, and light sources like streetlights). Traps are left out for 24hrs, after which moths are extracted and photographed, which is usually sufficient for identification via photo-recognition algorithms (these identification algorithms might have to be improved for southern and eastern European countries, further software development of these algorithms is not included in this cost overview). It is best to empty these traps early in the day, as when the moths warm up they are more likely to escape, and harder to photograph, or using a mosquito net if they are to be photographed later in the day. Five traps are placed during the first visit (when pan traps are placed and the first two transect walks take place) and collected the next day. Placement of a trap takes about 5 minutes; collection of a trap takes about 15 minutes. See Tables 5.17 and 5.18.

Table 5.17. Material costs for undertaking light traps

Component	Price (€/unit)	Units required	Expected lifetime	Costs (€/year)
Light trap (with battery and auto activation)	€ 110.00	5	5 years	€ 110.00
Mosquito net	€9.99	1	5 years	€2.00
Cardboard box (eggs)	€ 0.14	10	3 visits	€ 3.73
Average Costs/year				**€ 115.73**
Total annual consumable costs				€ 3.73
Additional costs/5 years				€ 110.00

Table 5.18. Time (hrs) required to undertake light traps

Task	Time (h/unit)	Units required	Frequency	Total hours/year
Deployment time	0.08	5	every visit	0.42
Collection time	0.25	5	every visit	1.25
Identifying photographs	0.34	1	every visit	1.25
Total hours/visit				1.67
Total hours/site/year				13.3

Table 5.19. Number of specimens sampled for lab ID/verification using transect walks and pan traps; * average catches are doubled as outlined above ** Breeze et al (2020) uses a figure of 3.44 specimens caught per professional transect round (with 4 transects, approximately 1.29/transect), assuming that all others are identified in situ. For the purposes of this report, we assume a professional is able to identify 50% more specimens in situ than a volunteer and thus will catch 50% fewer specimens for identification.

Method	Specimens for Lab ID*	Unit
Transect (Volunteers)	2.58**	Per transect
Transect (Professionals)	1.72	Per transect
Pan trap	7.68	Per pan trap triplet

5.5.1.4 Specimen processing time

Finally, for all methods, estimates of the number of samples that would require lab identification or verification were collected from Breeze et al (2020). These estimates come from UK field studies only and may be higher or lower in different regions, depending on the local pollinator density or the attractiveness of the surrounding floral resources (O'Connor et al., 2019). However, to date, we lack the standardised data required to explore the variation in these estimates or produce an average catcah per country (Table 5.19). As the UK is likely to have a significantly lower pollinator density than many southern European countries, to account for this variation, specimens captured are doubled.

5.5.2 Costings for different site networks

In order to operationalise these costs and evaluate the costs of a full EU pollinator monitoring network, a decision needs to be made as to how to distribute these sites across the different countries. Ideally, sites should be placed in a stratified-random manner that reflects pollinator biodiversity across Europe (section 5.2.1). However, lacking detailed information on the abundance and diversity of pollinator populations, such as will be gained from a monitoring network, it is difficult to accurately judge where to distribute sites. This, in turn, will have a significant impact on the costs of running such a network due to variation in the costs of staff and certain resources in different countries. Here we outline a number of methods to determine the number of sites in each of the 28 countries (the EU-27 and the UK). Note that the UK could participate in the site network, but all costs are presented as the EU27 only.

For this exercise, we assumed that approximately 2,100 sites would be required across Europe (see 5.2.1). The different distribution among the 28 countries is presented in Table 5.20. As the models often return non-integer numbers of sites for countries, all distributions per country are rounded to the nearest whole site, resulting in some distributions having more than 2,100 sites. A sensitivity analysis later in the chapter (5.5.7. and Appendix 5) presents the results for 2,500 and 3,000 site networks.

5.5.2.1 Equal Distribution

This model allocates an equal number of sites among each of the countries. Assuming a default minimum of 2,100 sites and rounding upwards, this results in 75 sites per country. This allocation model, although sharing effort equally among participating countries, results in small countries receiving a very high density of sites compared to larger ones that contain a greater proportion of Europe's pollinator diversity. It is included here only for comparative purposes to other models.

5.5.2.2 Area based distribution

This model distributes sites based on the size of each country (in km^2 - Eurostat, 2020) as a % of the total area of all 27 countries (4.1M km^2). Implemented solely commensurate with area, however, will result in smaller countries (e.g. Malta, Luxembourg) being allocated few to no sites, missing national scale losses of pollinator diversity and potentially many rare species. Instead, we assume that 10 sites are initially allocated to each country and then the remaining sites (1,820 in the default setting) are allocated based on area, ensuring that all countries have a minimum site network.

5.5.2.3 Area and Species based distribution

This model is identical to the area based distribution model above, including the 10 site initial allocation, except that only 50% of the remaining sites (910 sites in the default setting) are allocated based on area. The other 50% of remaining sites are distributed based on the total number of pollinator species in each country (from Chapter 7). The number of pollinator species is summed across all countries and member states receive a proportion of sites based on their contribution to this total value. This does not represent the contribution of each country to total EU or European pollinator diversity, it is only a mathematically simply way of apportioning sites based on total relative diversity. This model reduces the number of sites allocated to larger countries, particularly those with relatively low species diversity (in particular Finland and Sweden) but redistributes these sites to countries with smaller areas but relatively high diversity (in particular Slovenia and Greece). A national scale breakdown of the costs under this distribution model can be found in Appendix 5.5.

Table 5.20. Number of sites per country under each of the different distribution models. *The report was drafted during the process of UK exiting the EU. Therefore, EU refers to the 27 Member States comprising the EU, with separate reference to the UK as an additional country

Country	Model 1 (Equal)	Model 2 (Area based)	Model 3 (Area and species based)
Austria	75	45	70
Belgium	75	23	44
Bulgaria	75	56	71
Croatia	75	34	59
Cyprus	75	14	27
Czechia	75	43	63
Denmark	75	28	41
Estonia	75	28	38
Finland	75	150	103
France	75	238	181
Germany	75	159	124
Greece	75	65	96
Hungary	75	48	70
Ireland	75	39	33
Italy	75	136	131
Latvia	75	37	49

Country	Model 1 (Equal)	Model 2 (Area based)	Model 3 (Area and species based)
Lithuania	75	37	47
Luxembourg	75	12	32
Malta	75	10	15
Netherlands	75	26	43
Poland	75	141	110
Portugal	75	46	61
Romania	75	110	105
Slovakia	75	30	58
Slovenia	75	19	49
Spain	75	217	171
Sweden	75	197	129
UK*	75	114	82
Total	**2,100**	**2,102**	**2,102**
Total EU	**2,025**	**1,986**	**2,018**

5.5.3 International scheme costs

5.5.3.1 Staff and fuel costs

Although material costs for the methods outlined are not likely to vary much between most European countries, differences in wages are likely to cause large variations in the costs of monitoring. In order to address this, we contacted a number of European research groups (Appendix 5.4a) who are working on pollinators and asked them to supply information on the following costs:

- Administration costs: The annual salary and overheads for one experienced, full-time administrator, e.g. a senior administrator in a university department (not an entry level or secretarial position).

- Surveyor costs: The annual salary of a trained research technician who would be expected to go into the field and collect data for the duration of the season, e.g. a technician attached to a research project with at least degree level education.

- Identifier costs: The costs per day of a highly skilled taxonomist who would identify specimens collected, e.g. a very experienced research technician or a post-doctoral researcher

- Fuel costs: Typical fuel costs that can be claimed by staff per km travelled for field work purposes.

The responses given are typical of each country but some substantial variation in real costs may exist. Where multiple responses were received from each country, average values were used. For countries where no staff or mileage costs were available, costs were estimated using the average costs from 3 neighbouring countries (Appendix 5.4b) with similar national GDP/currency conversion were used (Eurostat, 2020). Where it was necessary to calculate daily or hourly wages, we assumed 220 working days and 7.5 hours per working day (as EU standard).

5.5.3.2 Postage costs

As it is very likely that schemes will not have sufficient taxonomic expertise for all specimens to be reliably identified by local recorders (Chapter 7), it will be necessary to post those specimens requiring identification to a central location for identification. The costs of posting materials were based on the costs of posting a 5kg box of dimensions 44 x 20 x 30cm (the size of two typical specimen boxes) using the international carriers TNT and DHL. Costs were estimated for both within country postage and for postage between each country and Germany (should a scheme wish to completely centralise identification).

In reality, these costs are likely to be an overestimate as local carriers may be substantially cheaper (as is the case in the UK and Netherlands) and, if a large bulk of samples were to be sent, specialist contracts could be issued that would substantially lower these costs.

5.5.3.3 Exchange Rates

Where it was necessary to convert currencies into €, we used average annual exchange rates from the year 2019 (European Central Bank, 2020). These are summarised in Appendix 5.4c.

5.5.4 Scheme assumptions and cost calculator

A number of assumptions were used to generate the scheme wide cost estimates, many of which can be varied within the cost calculator spreadsheet (Appendix 5.4.).

5.5.5 Caveats of costing methodology

Although every effort has been made to be as comprehensive as possible, a number of cost factors have not been included due to a lack of available data:

- DNA Barcoding: Instead of traditional taxonomic identification, DNA barcoding could be used as a viable alternative (see sections 8.6 and 8.7). However, the capacity for using this technology on such a scale in each country or centrally remains unknown, and the costs in terms of time, materials and overheads will vary to a significant degree between countries. As such, it was not feasible to estimate these costs for a Europe-wide monitoring scheme, however see Breeze et al. (2020) for an estimate of the costs in a UK context.

- Digital data management and website: The costs of managing a data management infrastructure project website are assumed to be included within the overhead costs of the project, however depending on the nature and complexity of the scheme and its requirements for access this cost could vary substantially and may require a specialist administrator to run.

5.5.6 Estimated costs of the EU Pollinator Monitoring Scheme

Following the assumptions above, we estimated the costs of running the Europe-wide pollinator monitoring scheme as described previously, with 2,100 sites, sampled 8 times per year over 10 years. Each site is sampled with transects (4/site), pan traps (10 triplets/site) with 50% professional (5 sites each) and 50% volunteer recorders (1 site each) travelling an average of 120 km (round trip) per site. Identification was assumed to be conducted in the country and administration was centralised (in Belgium for this calculation but could be elsewhere) with 1 administrator per 250 sites (8 total).

As noted previously, these calculations were made on the basis that the UK would participate in the site network, however all costs presented subsequently are for the EU only unless otherwise noted.

We estimate that the Minimum Viable Scheme across the EU will cost between €128.5M and €133.3M in total over the full 10-year lifespan (Table 5.21), depending on the scheme chosen. In the first year, an additional investment of ~€0.2M is required. The area-based distribution (model 2) is the most expensive as many countries with large areas have the highest staff costs (specifically France, Sweden and Finland). The fixed network is the least costly but presents significant limitations as large countries will be allocated fewer sites while very small countries will be allocated more sites than could be realistically placed independently.

Table 5.21. Total Scheme costs for the sample monitoring scheme under the three distribution models (over 10 years).

Distribution	Sites	Total (EU)	Year 1 cost (EU)	Average annual cost (EU)
1: Equal	2,100	€ 128,503,473	€ 13,061,853	€ 12,850,347
2: Area based	2,102	€ 133,345,870	€ 13,541,722	€ 13,334,587
3: Species & Area based	2,102	€ 130,405,182	€ 13,250,634	€ 13,040,518

We henceforth use allocation Model 2 as the basis for our monitoring scheme recommendations. This provides greatest potential for reporting by Member States and will give a representative sample of the EU and forms the basis for all further recommendations for this pilot phase. Note that while this distribution model does include the UK, costs associated with the UK are not included in the discussion unless otherwise noted.

5.5.6.1 Cost Sensitivity

To illustrate the sensitivity of the costing estimates to changes in different aspects of scheme structure, we used the Cost Calculator spreadsheet (link and instructions in Appendix 5.4.) to vary one aspect of the scheme at a time, keeping all other variables as per the default scheme (Table 5.22). A more detailed sensitivity analysis comparing the changes in multiple variables simultaneously and between models 2 and 3 is available in Appendix 5.

Increasing the number of sites in the network to 2,500 or 3,000 to account for more sensitive detection will increase costs by €25.5M and €57.3M over the 10-year period (total costs €158.9M and €190.7M respectively) Detailed breakdowns of these costs at a country level are presented in Annex 5.5.

- Reducing the years of the scheme to 7 (from 10) to account for EU policy cycles resulted in a reduction of ~€39.9M compared to a 10-year scheme (total EU cost: €93.4M) but the costs per country per year remain more or less the same. Continued monitoring would be required in subsequent funding cycles to assess the status of pollinating insects.

- Changing the number of sampling rounds to 4 or 6 (from 8) to reflect a less intensive monitoring scheme, reduces total 10-year costs by €58M (total EU cost: €75.2M) and €29M (total EU cost €104.3M) respectively. However, such a reduction in sampling rounds risks failing to sample sites intensively enough to be able to detect changes at the levels proposed in section 5.2. and would likely miss the active periods of many species in southern countries.

- If transect surveys were to be conducted during both the deployment and collection of pan traps, resulting in 8 transects per site per round, 10-year costs would increase by ~€12.8M (total EU cost: €146.2M) due to the greater time investment and higher number of specimens caught for identification.

- Adding light traps to the default scheme to capture a broader range of taxa increased total 10-year costs by ~€8.5M (total EU cost: €141.8M). This represents a considerable expansion in species detection for a relatively low cost. A more detailed assessment of this add-on, with a fully professional monitoring staff, is available in appendix 5.5.

– Increasing the distance between sites (round trip) to 200 km, to account for a more dispersed network, increased total 10-year costs by ~€14.5M (total EU cost: €147.8M). This may be especially relevant to geographically larger countries where sites may be more dispersed.

– Removing species level identification, and thus the need for professional identification staff, reduced costs by ~€42M (total EU cost: €91.4M). However, this would undermine the ability to generate species level indicators and result in much lower overall data quality delivered from the EU-PoMS. Furthermore, the development of indicators within this report is contingent on species-level information.

– A network with 100% professional recorders, reflecting the highest quality data collection strategy (assuming highly trained recorders), would increase total 10-year costs by ~€29.8M (total EU costs: €163.1M). Conversely, a scheme with 100% volunteer records, reflecting efforts to maximise public engagement would reduce total 10-year costs by approximately €29.7M (total EU costs: €103.7M). Countries with well-established volunteer recorder communities would have a higher proportion of volunteers, whereas those without these communities would have a higher proportion of professionals but we would expect this proportion to drop as public engagement and training to build in country capacity progressed. A fully volunteer-based approach is unlikely to be feasible without several years of investment in capacity building and training.

– A scheme with regional administration hubs with lower overheads than a central scheme (using Sweden, Poland, Greece and the Netherlands as examples), would reduce the total 10-year costs by €6.3M (total EU costs: €127M). This may add complexity to implementation as it requires further collaboration across Member States to harmonise data management and access. Transaction costs associated with this are not included and difficult to estimate.

– By contrast, a scheme with national, rather than centralised administration, increases total 10- year costs by ~€4.3M (total EU costs: €137.6M) due to the greater number of administrative staff required. As above, however, this would increase the administrative complexity and will likely incur considerable transaction costs as well.

Table 5.22. Summary of scheme costs when altering different individual caveats, using distribution model 2 as a baseline. *Default is 10 years, 8 replicates per year, no light traps, 120 km distance to site, species level ID, 50% professional/50% volunteer recorders, central administration (Belgium) and including the UK in the site network but not the total costs. All cost variants only alter the factor listed, all other factors in the scheme are held constant (e.g. a 67-year scheme is still 50% professional, 50% volunteer recorders, 8 rounds/year, etc.)

Cost Variant	Sites	Total costs	Year 1 cost	Average annual cost	Change in Total costs
Default*	2,102	€ 133,345,870	€ 13,541,722	€ 13,334,587	
2,500 sites	2,503	€ 158,875,352	€ 16,133,751	€ 15,887,535	€ 25,529,482
3,000 sites	3,003	€ 190,725,970	€ 19,368,073	€ 19,072,597	€ 57,380,100
7 Year scheme	2,102	€ 93,423,498	€ 13,541,722	€ 13,334,587	-€ 39,922,372
4 Sampling rounds/year	2,102	€ 75,268,150	€ 7,733,949	€ 7,526,815	-€ 58,077,720
6 sampling rounds/year	2,102	€ 104,307,010	€ 10,637,835	€ 10,430,701	-€ 29,038,860
8 Transects	2,012	€ 146,189,132	€ 14,826,048	€ 14,618,913	€ 12,843,262
With light traps	2,102	€ 141,800,613	€ 14,916,076	€ 14,180,061	€ 8,454,743
200 km distance to sites (round trip)	2,102	€ 147,833,319	€ 14,990,728	€ 14,783,332	€ 14,487,449
No species level ID	2,102	€ 91,395,073	€ 9,346,642	€ 9,139,507	-€ 41,950,797
100% professional recorders	2,102	€ 163,127,425	€ 16,661,548	€ 16,312,742	€ 29,781,555
100% volunteer recorders	2,102	€ 103,695,169	€ 10,434,851	€ 10,369,517	-€ 29,650,701
Regional administration	2,102	€ 127,013,826	€ 12,908,517	€ 12,701,383	-€ 6,332,044
Local administration	2,102	€ 137,623,203	€ 13,969,455	€ 13,762,320	€ 4,277,333
Bespoke volunteer training	2,102	€ 209,595,826	€ 19,622,825	€ 19,415,690	€ 76,249,956
Scheme does not include the UK	2,102	€ 140,102,266	€ 14,229,141	€ 14,010,227	€ 6,756,396

– Including fully bespoke volunteer training where each volunteer is given one-to-one training on the methods used at the start of the project would add €76.2M (total EU costs €209.6M). This would provide the highest quality training to volunteers and may, in turn, increase volunteer retention, which would drive this cost down as less subsequent training would be required.

– Removing the UK from the scheme will change the distribution of sites, with almost all countries within the EU having more sites. The total costs for EU member states would increase by €6.8M (total EU costs €140.1M) due to an increase in each Member State's costs. This would also decrease the geographic coverage and diversity of the scheme from a scientific standpoint.

5.5.7 Estimated costs of the scheme for each Member State

Working on the basis that area-based distribution of sites (with a minimum of 10 sites per Member State, see Model 2 above) across Member States would give the most representative monitoring scheme across the EU as a whole, we then broke down costs into a per country basis. As above, each site is assumed to have 4 transects and 10 pan trap triplets each, sampled 8 times per year with 50% of sites sampled by professionals and 50% by volunteers, travelling an average of 120 km to and from each site and species level Identification.

These national costs (Table 5.23) were divided into establishment (start-up) costs and annual monitoring costs. Start-up costs, the costs of long-lasting material components such as nets and pan traps, are mostly driven by the number of sites in each country but are also influenced by the average postage costs (hence e.g. Sweden has higher costs than Germany). These costs were relatively small, ranging from €1,300 (Malta) to €32,400 (France).

Annual monitoring costs are the full costs of annual wages for staff, consumable materials, fuel, travel, accommodation, postage of samples, sample identification and training events. These costs were also influenced to a minor extent by a number of factors, such as typical wages for different staff, the relative strength of the currency to the Euro, the costs of postage materials and the typical fuel costs. However, the number of sites was again the biggest driver of differences in costs, ranging from €53,000/year in Malta, where only a single professional member of staff is required, to €1.8M in France where 24 professionals are required and wages are relatively high compared to many other countries. Spain, Sweden, Germany and Finland are also projected to cost more than €1M per year due to the number of sites involved, and the high relative staff costs in Sweden and Finland. For most (21 of 27) countries, annual costs were less than €500,000/year.

Pollinator training, Una FitzPatrick

Table 5.23. Summary of scheme costs in each Member State. Sites: the number of sites to be monitored in each country based on a 2,100 site network (2,103 due to rounding during site distribution) with a minimum of 10 sites per country and all other sites distributed by area (see Model 2a, section 5.5.2.2.). Start-Up costs: all non-consumable materials necessary to sample the network over its 10-year lifespan (e.g. nets, pan traps etc., see 5.4.1.) and the costs of posting this material to participants. Annual costs: the costs of annual wages, accommodation on field work, fuel, consumable materials (e.g. alcohol for storing specimens), identification of specimens, sample and material postage and training (see 5.4.3). *Note that in the default assumptions of the scheme, Belgium would host the scheme administration at a cost of €1.5M/ year, however this could potentially come from central EU funds rather than national government. As such, it is included in the final total but not the national costs. **The report was drafted during the process of UK exiting the EU. Therefore, EU refers to the 27 Member States comprising the EU, with separate reference to the UK as an additional country.

Country	Sites	Establishment costs	Annual costs	Total costs (10 years)
Austria	45	€ 6,120	€ 345,371	€ 3,459,833
Belgium*	23	€ 3,116	€ 174,159	€ 1,774,705
Bulgaria	56	€ 7,469	€ 176,718	€ 1,774,648
Croatia	34	€ 4,568	€ 108,454	€ 1,089,106
Cyprus	14	€ 1,821	€ 69,075	€ 692,568
Czechia	43	€ 5,860	€ 159,486	€ 1,600,724
Denmark	28	€ 3,945	€ 227,429	€ 2,278,234
Estonia	28	€ 3,802	€ 135,613	€ 1,359,930
Finland	150	€ 20,641	€ 1,190,286	€ 11,923,506
France	238	€ 32,407	€ 1,794,404	€ 17,976,448
Germany	159	€ 21,907	€ 1,117,949	€ 11,201,397
Greece	65	€ 8,905	€ 290,036	€ 2,909,264
Hungary	48	€ 6,404	€ 172,134	€ 1,727,744
Ireland	39	€ 5,367	€ 259,790	€ 2,603,269
Italy	136	€ 18,458	€ 872,994	€ 8,748,399

Latvia	37	€ 5,064	€ 161,180	€ 1,616,867
Lithuania	37	€ 5,031	€ 190,642	€ 1,911,455
Luxembourg	12	€ 1,577	€ 100,490	€ 1,006,474
Malta	10	€ 1,329	€ 53,308	€ 534,412
Netherlands	26	€ 3,596	€ 219,174	€ 2,195,333
Poland	141	€ 18,777	€ 428,746	€ 4,306,237
Portugal	46	€ 6,209	€ 245,844	€ 2,464,651
Romania	110	€ 14,563	€ 312,491	€ 3,139,477
Slovakia	30	€ 3,985	€ 110,381	€ 1,107,792
Slovenia	19	€ 2,602	€ 96,172	€ 964,324
Spain	217	€ 29,206	€ 1,303,145	€ 13,060,655
Sweden	197	€ 28,568	€ 1,555,406	€ 15,582,626
UK**	114	€ 15,248	€ 1,000,245	€ 10,017,695
Total	**2,102**	**€ 286,545**	**€ 9,744,426**	**€ 143,363,565**
Total EU	**1,988**	**€ 271,297**	**€ 9,001,398**	**€ 133,345,870**

These costs would vary more if the number of sampling rounds was varied between countries to account for the length of the season during which pollinators are active. For example, reducing the number of sampling rounds to 6 in Sweden, Finland and Austria where the colder or mountainous climate limits the flying season for most pollinators, would save around €247,000, €204,000 and €62,000 respectively. Similarly, increasing the sampling rounds in warmer, southern countries (e.g. Italy, Malta, Cyprus, Greece, Spain and Portugal) where a wider number of pollinator species are active over more of the year, would increase costs by between ~€9,600 (Malta) and ~€233,000 (Spain). Again, this trend is driven mostly by the number of sites. Costs could be further reduced by increasing the proportion of volunteer-managed sites, however this may leave the scheme vulnerable to volunteers dropping and potentially lower data collection quality if insufficient training and support was available, potentially jeopardising overall effectiveness (O'Connor et al., 2019), and may prove very difficult in countries with lower population densities.

5.6 Options for linking to existing pollinator monitoring schemes

Several Member States are already implementing pollinator monitoring schemes, or plan to do so. A Europe-wide pollinator scheme should complement existing activities as far as possible, while still meeting the core criteria of the EU-PoMS design.

The first key consideration is the need for standardisation of sampling methods, with consistent approaches for pan traps and transects deployed across all Member States. Without identical sampling methods, it is near impossible to generate meaningful and robust indicators at Member State and EU levels. We therefore recommend a Minimum Viable Scheme to comprise both pan traps and transect counts using the methods in section 5.2.3 and refined through piloting (sections 9.1 and 9.2). Member States that have already implemented pollinator monitoring schemes would therefore either need to adapt their current sampling methods, or implement the EU-PoMS methodologies in parallel, in order to be able to contribute to an EU Pollinator Monitoring Scheme. For example, Member States that currently only sample selected pollinator groups (e.g. only bumble bees and butterflies) using transects would need to implement transect counts for more taxonomic groups (e.g. hoverflies, solitary bees) and instigate a pan trap network. Similarly, Member States with only pan trap networks would need to supplement them with transect counts for all four main pollinator groups (butterflies, hoverflies, solitary bees, bumble bees).

The second key consideration is the allocation of sampling sites. The core EU-PoMS design allocates sites on a stratified-random basis within each Member State to be representative of the main land use coverage. This standardised approach is critical to be able to generate robust indicators at the Member State and EU and to allow comparability spatially and temporally. Where existing pollinator monitoring schemes are in place, then existing scheme sites should be incorporated into EU-PoMS sites as far as possible, while maintaining the EU-PoMS site allocation criteria. For countries with eBMS networks (see Table 5.11), this will lead to some replication of butterfly transects within a country between eBMS and EU-PoMS sites. This is inevitable as the majority of existing butterfly transects are selected by volunteers (often on the basis of having rich butterfly communities and/

or being readily accessible) rather than being systematically allocated to be representative of land use. It will not be possible to only use eBMS transects, and add in pan trapping protocols, as this approach will not allow the robust indicators required for the EU Pollinator Initiative to be generated at MS and EU level. Also, it cannot be assumed that eBMS volunteer recorders will adopt EU-PoMS methodologies in addition to the butterfly transect walks, although including bumble bees may be feasible on some sites. Similarly, other non-eBMS monitoring schemes could add in additional sites and methods to be incorporated into the EU-PoMS. Although alignment of sites between eBMS and EU-PoMS is not practicable, eBMS networks have additional benefits. For example, a major advantage of eBMS transect sites over those within the EU-PoMS is that they have more frequent sampling each year, with a weekly protocol in most schemes. This provides accurate estimates of species' flight periods that can be used to standardise EU-PoMS butterfly counts. eBMS transects also tend to sample areas rich in butterflies and locations of rare and threatened species. For countries with both eBMS and EU-PoMS butterfly transects, data can be integrated and appropriately weighted within statistical models to produce national trends and indicators that are likely to be more robust and representative than either scheme would provide alone (Isaac et al. 2020). Volunteer-based Butterfly Monitoring Schemes should ideally be established in all EU Member States to contribute to the EU-PoMS and research into factors affecting insect populations, as well as building capacity in insect monitoring more widely.

Prior to the full implementation of EU-PoMS, we recommended a more detailed evaluation for integration of existing monitoring schemes.

References

Bernays E.A, Singer M.S, & Rodrigues, D (2004) Foraging in nature: foraging efficiency and attentiveness in caterpillars with different diet breaths. *Ecological Entomology*, 29, 389–397.

Bertin RI & Willson MF (1980) Effectiveness of diurnal and nocturnal pollination of two milkweeds. *Canadian Journal of Botany*, 58(16), 1744–1746.

Breeze TD, Bailey AP, Balcombe KG, Brereton T, Comont R, Edwards M, Garratt MP, Harvey M, Hawes C, Isaac N, Jitlal M, Jones C, Kunin WE, Lee P, Morris RKA, Musgrove A, O'Connor RS, Peyton J, Potts SG, Roberts SPM, Roy DB, Roy HE, Tang CQ, Vanbergen AJ and Carvell C (2020) Pollinator Monitoring More than Pays for Itself. *Journal of Applied Ecology.* https://doi.org/10.1111/1365-2664.13755

Buchholz S & Kowarik I (2019) Urbanisation modulates plant-pollinator interactions in invasive vs. native plant species. *Scientific Reports*, 9, 6375

Buckland S & Johnston A (2017) Monitoring the biodiversity of regions: Key principles and possible pitfalls. *Biological Conservation*, 214, 23–34.

Buckland S, Baillie S, Dick JM, Elston D, Magurran A, Scott E, Smith R, Somerfield P, Studeny A. & Watt A (2012) How should regional biodiversity be monitored? *Environmental and ecological statistics*, 19, 601–626.

Carvell C, Osborne JL, Bourke AFG, Freeman SN, Pywell, RF & Heard MS (2011) Bumble bee species' responses to a targeted conservation measure depend on landscape context and habitat quality. *Ecological Applications*, 21(5), pp. 1760–1771.

Carvell C, Harvey M, Mitschunas N, Beckmann B, Isaac NJB, Powney GD, … Roy HE (2020) Establishing a UK Pollinator Monitoring and Research Partnership (PMRP). Final report to the Department for Environment, Food and Rural Affairs (Defra), Scottish Government, Welsh Government and JNCC: Project BE0125.

Carvell C, Isaac N, Jitlal M, Peyton J, Powney G, Roy D, Vanbergen A, O'Connor R, Jones C, Kunin B, Breeze T, Garratt M, Potts S, Harvey M, Ansine J, Comont R, Lee P, Edwards M, Roberts S, Morris R, Musgrove A, Brereton T, Hawes C & Roy H (2016) *Design and testing of a national pollinator and pollination monitoring framework*. Wallingford, NERC/Centre for Ecology & Hydrology, 62 pp.

Carvell C, Osborne JL, Bourke AFG, Freeman SN, Pywell RF and Heard MS (2011) Bumble bee species' responses to a targeted conservation measure depend on landscape context and habitat quality. *Ecological Applications,* 21, 1760 - 1771.

Deguines N, Julliard R, de Flores M & Fontaine C (2012) The Whereabouts of Flower Visitors: Contrasting Land-Use Preferences Revealed by a Country-Wide Survey Based on Citizen Science. *PLOS ONE* 7(9): e45822.

Devoto M, Bailey S & Memmott J (2011) The 'night shift': nocturnal pollen-transport networks in a boreal pine forest. *Ecological Entomology*, 36(1), 25–35.

Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Chowdhury RR, Shin Y-J, Visseren-Hamakers I, Willis KJ & Zayas CN (2019) Pervasive human-driven decline of life on Earth points to the need for transformative change. *Science*, 366.

European Central Bank (2020) Exchange rates (2019 annual average) – conversion of local currency into one Euro http://sdw.ecb.europa.eu/browse.do?node=9691296

Eurostat (2020a) Land cover overview by NUTS 2 regions, https://appsso.eurostat.ec.europa.eu/nui/show.do

Fleming TH, Tuttle MD, & Horner MA (1996) Pollination biology and the relative importance of nocturnal and diurnal pollinators in three species of Sonoran Desert columnar cacti. *The Southwestern Naturalist*, 257–269.

Fox R (2013) The decline of moths in Great Britain: A review of possible causes. *Insect Conservation and Diversity*, 6, 5–19.

Franklin AJ, Liebhold AM, Murray K & Donahue C (2003) Canopy herbivore community structure: large-scale geographical variation and relation to forest composition. *Ecological Entomology*, 28, 278–290.

Garratt MPD, Breeze T, Jenner N, Polce C, Biesmeijer JC, Potts SG (2014a) Avoiding a bad apple: insect pollination enhances fruit quality and economic value. *Agriculture, Ecosystems and Environment*, 184: 34–40

Garratt MPD, Coston DJ, Truslove CL, Lappage MG, Polce C, Dean R, Biesmeijer JC, Potts SG (2014b) The identity of crop pollinators helps target conservation for improved ecosystem services. *Biological Conservation,* 169: 128–135

Garratt MPD, Potts SG, Banks G, Hawes C, Breeze TD, O'Connor RS & Carvell C. (2019) Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services. *Global Ecology and Conservation*, 20, e00781.

Gregory RD, van Strien A, Vorisek P, Meyling AWG, Noble DG, Foppen RPB, and Gibbons DW (2005) Developing indicators for European birds. *Philosophical Transactions- Royal Society of London Series B Biological Sciences*, 269–288.

Hahn M, & Brühl CA (2016) The secret pollinators: an overview of moth pollination with a focus on Europe and North America. Arthropod-Plant Interactions, 10(1), 21–28.

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T and Goulson D. (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. *PloS one*, 12(10), p.e0185809.

Hering D, Borja A, Carstensen J, Carvalho L, Elliott M, Feld CK, Heiskanen AS, Johnson RK, Moe J, Pont D. & Solheim AL (2010) The European Water Framework Directive at the age of 10: a critical review of the achievements with recommendations for the future. *Science of the total Environment*, 408(19), 4007–4019.

Hilborn R (1987) Living with Uncertainty in Resource Management. *North American Journal of Fisheries Management*, 7, 1–5.

Isaac NJ, Jarzyna MA, Keil P, Dambly LI, Boersch-Supan PH, Browning E, Freeman SN, Golding N, Guillera-Arroita G, Henrys PA & Jarvis S (2020) Data integration for large-scale models of species distributions. *Trends in ecology & evolution*, 35(1), 56–67.

Kaiser-Bunbury CN, Mougal J, Whittington AE, Valentin T, Gabriel R, Olesen JM & Blüthgen N (2017) Ecosystem restoration strengthens pollination network resilience and function. *Nature*, 542(7640), 223–227.

Le Féon V, Henry M, Guilbaud L, Coiffait-Gombault C, Dufrêne E, Kolodziejczyk E, Kuhlmann M, Requier F & Vaissière BE (2016) An expert-assisted citizen science program involving agricultural high schools provides national patterns on bee species assemblages. *Journal of Insect Conservation*, 20(5), 905–918.

Lyneborg L, Nielsen PS, Razowski J & Karsholt O (1996) *The Lepidoptera of Europe: A Distributional Checklist*. Apollo books.

Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein AM, Kremen C, M'gonigle LK, Rader R. & Ricketts TH (2015). Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. *Nature communications*, 6(1), 1–9.

LeBuhn G, Droege S, Connor EF, Gemmill-Herren B, Potts SG, Minckley RL, Griswold T, Jean R, Kula E, Roubik, DW, Cane, J, Wetherill K, Frankie G, and Parker F. 2013. Detecting insect pollinator declines on regional and global scales. *Conservation Biology,* 27 ,113–120.

Le Féon V, et al. (2016) An expert-assisted citizen science program involving agricultural high schools provides national patterns on bee species assemblages. J Insect Conserv 20, 905–918

Macgregor CJ, Kitson JJ, Fox R, Hahn C, Lunt DH, Pocock MJ, & Evans DM (2019) Construction, validation, and application of nocturnal pollen transport networks in an agro-ecosystem: a comparison using light microscopy and DNA metabarcoding. *Ecological entomology*, 44(1), 17–29.

Macgregor CJ, Pocock MJ, Fox R, & Evans DM (2015) Pollination by nocturnal L epidoptera, and the effects of light pollution: a review. *Ecological entomology*, 40(3), 187–198.

McDonald-Madden E, Baxter PW, Fuller RA, Martin TG, Game ET, Montambault J and Possingham HP (2010) Monitoring does not always count. *Trends in Ecology & Evolution*, 25(10), 547–550.

Miyake T & Yahara T (1999) Theoretical evaluation of pollen transfer by nocturnal and diurnal pollinators: when should a flower open? *Oikos*, 233–240.

Nichols JD & Williams BK (2006) Monitoring for conservation. *Trends in Ecology & Evolution* 21:668–673.

Nieto A, Roberts SP, Kemp J, Rasmont P, Kuhlmann M, García Criado M, Biesmeijer JC, Bogusch P, Dathe HH, De la Rúa P & De Meulemeester T. et al. (2014) European red list of bees.

O'Connor RS, Kunin WE, Garratt MP, Potts SG, Roy HE, Andrews C, Jones CM, Peyton JM, Savage J, Harvey MC & Morris RK (2019) Monitoring insect pollinators and flower visitation: the effectiveness and feasibility of different survey methods. *Methods in Ecology and Evolution*, 10(12), 2129–2140.

Outhwaite CL, Gregory RD, Chandler RE, Collen B and Isaac NJ (2020) Complex long-term biodiversity change among invertebrates, bryophytes and lichens. Nature Ecology & Evolution, 4(3), pp. 384–392.

Pescott OL, Walker KJ, Pocock MJ, Jitlal M, Outhwaite CL, Cheffings CM, Harris F & Roy DB (2015) Ecological monitoring with citizen science: the design and implementation of schemes for recording plants in Britain and Ireland. *Biological Journal of the Linnean Society*, 115, 505–521.

Pocock MJ, Evans DM, Fontaine C, Harvey M, Julliard R, McLaughlin Ó, Silvertown J, Tamaddoni-Nezhad A, White PC & Bohan DA (2016) *The visualisation of ecological networks, and their use as a tool for engagement, advocacy and management*. In: Advances in Ecological Research (Vol. 54, pp. 41–85). Academic Press.

Possingham HP, Fuller RA and Joseph LN (2012) *Choosing among long-term ecological monitoring programs and knowing when to stop*. Design and analysis of long-term ecological monitoring studies. Edited by Robert .A. Gitzen, Joshua J. Millspaugh, Andrew B. Cooper and Daniel S. Licht.. Cambridge: Cambridge University Press. 498–508.

Power AG (2010) Ecosystem services and agriculture: tradeoffs and synergies. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 365(1554), 2959–2971.

Rákosy L, & Schmitt T (2011) Are butterflies and moths suitable ecological indicator systems for restoration measures of semi-natural calcareous grassland habitats? *Ecological Indicators*, 11, 1040–1045.

Reis S, Bekunda M, Howard CM, Karanja N, Winiwarter W, Yan X, Bleeker A & Sutton MA (2016) Synthesis and review: tackling the nitrogen management challenge: from global to local scales. *Environmental Research Letters*, 11(12), p.120205.

Rich C, & Longcore T (Eds) (2006) *Ecological consequences of artificial night lighting*. Washington, DC: Island Press.

Ricketts TH, Regetz J, Steffan-Dewenter I, Cunningham SA, Kremen C, Bogdanski A, Mayfield MM (2008) Landscape effects on crop pollination services: are there general patterns? *Ecology Letters*, 11(5), 499–515.

Roy DB, Rothery P & Brereton T (2007) Reduced-effort schemes for monitoring butterfly populations. *Journal of Applied Ecology*, 44, 993–1000.

Sierro A, Arlettaz R, Naef-Daenzer B, Strebel S & Zbinden N (2001). Habitat use and foraging ecology of the nightjar (Caprimulgus europaeus) in the Swiss Alps: towards a conservation scheme. *Biological Conservation*, 98, 325–331.

Singer MS, Farkas TE, Skorik CM & Mooney KA (2012). Tritrophic interactions at a community level: effects of host plant species quality on bird predation of caterpillars. *The American Naturalist*, 179, 363–374.

Stout JC & Tiedeken EJ (2017). Direct interactions between invasive plants and native pollinators: evidence, impacts and approaches. *Functional Ecology*, 31, 38–46.

Stuart SN, Wilson EO, McNeely JA, Mittermeier RA & Rodríguez JP (2010) The Barometer of Life. *Science*, 328, 177

Thompson S (2012). *Estimating proportions, ratios, and subpopulation means.* Sampling. John Wiley & Sons, Hoboken, New Jersey, 57–66.

Threlfall CG, Law B & Banks PB (2012). Sensitivity of insectivorous bats to urbanization: Implications for suburban conservation planning. *Biological Conservation*, 146, 41–52.

Tóth G, Jones A & Montanarella L. (2013). *The LUCAS topsoil database and derived information on the regional variability of cropland topsoil properties in the European Union.* Environmental monitoring and assessment, 185(9), pp. 7409–7425.

van Langevelde F & Braamburg-Annegarn M, Huigens ME, Groendijk R, Poitevin O, van Deijk J, Ellis WN, van Grunsven R, de Vos R, Vos RA, Franzén M & WallisDeVries MF (2018). Declines in moth populations stress the need for conserving dark nights. *Global Change Biology* 24(3), 925–932.

van Swaay CA, Nowicki P, Settele J, & Van Strien AJ. 2008. Butterfly monitoring in Europe: methods, applications and perspectives. *Biodiversity and Conservation*, 17 ,3455–3469.

van Klink R, Bowler DE, Gongalsky KB, Swengel AB, Gentile A and Chase JM, 2020. Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. Science, 368(6489), pp. 417–420.

VanZandt PA, Johnson DD, Hartley C, LeCroy KA, Shew HW, Davis BT, & Lehnert MS. (2020). Which moths might be pollinators? Approaches in the search for the flower-visiting needles in the Lepidopteran haystack. *Ecological Entomology*, 45(1), 13–25.

Walton RE, Sayer CD, Bennion H & Axmacher JC (2020). Nocturnal pollinators strongly contribute to pollen transport of wild flowers in an agricultural landscape. *Biology Letters*, 16(5), p. 20190877.

Wintle BA, Runge MC & Bekessy SA (2010). Allocating monitoring effort in the face of unknown unknowns. *Ecology Letters* 13 , 1325–1337.

Woodcock BA, Harrower C, Redhead J, Edwards M, Vanbergen AJ, Heard MS, Roy DB and Pywell RF, 2014. National patterns of functional diversity and redundancy in predatory ground beetles and bees associated with key UK arable crops. *Journal of Applied Ecology*, 51(1), 142–151.

Young HJ (2002). Diurnal and nocturnal pollination of *Silene alba* (Caryophyllaceae). *American Journal of Botany*, 89(3), 433–440.

Appendices

Appendix 5.1. Technical background to the statistical simulations of the expected counts

The expected count of species X at time t (X_t) can be said to be associated with the count at time zero and the slope over time. We can state that the natural logarithm of species X at time t will have a linear relationship with the intercept and slope:

$$\log\left(X_t\right) = \beta_0 + \beta_1 x \text{ Year }_t$$

Now assume that the intercept varies according to site i; and also that the slope varies by site:

$$\log\left(X_{it}\right) = \beta_{0i} + \beta_{1i} x \text{ Year }_{it}$$

We can also state that the logarithm of the expected count at time t is normally distributed around a mean μ_t and variance σ_t^2

$$\log\left(X_t\right) \sim N\left(\mu_t, \sigma_t^2\right)$$

Therefore the expected count at time t (X_t) can be said to be log-normally distributed with a mean m_t and variance v_t:

$$X_t \sim \text{lognormal}\left(m_t, v_t\right)$$

Note that the variances on the log scale follow the basic property:

$$\sigma_t^2 = \sigma_{\beta_{0t}}^2 + \sigma_{\beta_{1t}}^2 x \text{ Year}_t^2$$, but

$$v_t \neq v_{\beta_{0t}} + v_{\beta_{1t}} xYear_t^2$$

Note the following relationships between the normal parameters and the log-normal parameters:

$$\mu_t = \log\left[\frac{m_t^2}{\sqrt{m_t^2 + v_t}}\right]$$

$$\sigma_t^2 = \log\left[\frac{m_t^2 + v_t}{m_t^2}\right]$$

$$m_t = \exp\left(\mu_t +^{\sigma_t 2} /_2\right)$$

$$v_t = \exp\left(2\mu_t + 2\sigma_t^2\right) - \exp\left(2\mu_t + \sigma_t^2\right)$$

These can be used to calculate , which is equivalent to.

$$m_0 = \exp\left(\mu_0 +^{\sigma_0^2} /_2\right)$$

$$\rightarrow$$

$$\mu_0 = \log\left(m_0\right) - \frac{\sigma_0^2}{2}$$

where m_o is the initial expected count and $\sigma_0^2 = \sigma_{\beta_{00}}^2$. The only parameter that it is difficult to manipulate directly is v_t, the variance of the expected counts.

Appendix 5.2. Variability in counts of individual butterfly species

Appendix 5.3: Detailed national costs of professional moth monitoring

As the Light trap methodology relies upon visual identification, it would be necessary to employ professional recorders for all sites until the relevant visual technology is available across Europe. Hence, we present an additional costs analysis on a country-by -country basis. This assessment includes part of the costs of developing the visual technology (section 7.2.8) to identify moths from photographs, using expert recorders to manually identify and photograph specimens to build the relevant visual database. The costs therefore only cover the additional time spent to deploy, collect and identify light trap samples.

Species	Scheme	Typical initial annual count per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Aglais io	Germany BMS	15.6 (1682.46)	9.030	0.127
Aglais urticae	Germany BMS	12.82 (1782.49)	4.198	0.130
Anthocharis cardamines	Germany BMS	7.05 (604.37)	9.894	0.156
Aphantopus hyperantus	Germany BMS	40.36 (7117.66)	5.231	0.132
Argynnis aglaja	Germany BMS	0.65 (20.92)	7.702	0.414
Argynnis paphia	Germany BMS	7.02 (2057.59)	4.698	0.482
Callophrys rubi	Germany BMS	0.68 (38.86)	8.244	0.424
Celastrina argiolus	Germany BMS	3.55 (75.9)	3.581	0.184
Coenonympha pamphilus	Germany BMS	34.29 (4992.36)	4.332	0.177
Gonepteryx rhamni	Germany BMS	14.77 (2626.92)	5.175	0.170
Lycaena phlaeas	Germany BMS	6.2 (327.3)	4.221	0.154
Maniola jurtina	Germany BMS	63.67 (20552.67)	4.440	0.160
Ochlodes sylvanus	Germany BMS	9.13 (439.42)	3.605	0.215
Pararge aegeria	Germany BMS	4.12 (191.48)	4.020	0.259
Pieris brassicae	Germany BMS	23.47 (2867.59)	3.416	0.181
Pieris napi	Germany BMS	44.2 (10514.93)	4.602	0.148
Pieris rapae	Germany BMS	48.28 (10956.78)	4.107	0.207
Polyommatus icarus	Germany BMS	24.23 (3903.19)	3.544	0.252
Thymelicus lineola	Germany BMS	8.97 (544.3)	3.953	0.322
Aglais io	Catalonia BMS	5.97 (213.65)	4.318	0.042
Aglais urticae	Catalonia BMS	3.28 (140.59)	3.752	0.194
Anthocharis cardamines	Catalonia BMS	9.07 (252.2)	3.184	0.123
Argynnis aglaja	Catalonia BMS	0.8 (7.75)	6.764	0.303
Argynnis paphia	Catalonia BMS	18.02 (2891.83)	3.554	0.185
Callophrys rubi	Catalonia BMS	25.26 (3460.38)	3.687	0.151
Celastrina argiolus	Catalonia BMS	32.74 (22097.33)	2.327	0.124
Coenonympha pamphilus	Catalonia BMS	27.04 (6928.72)	4.131	0.207
Gonepteryx rhamni	Catalonia BMS	20.71 (1078.81)	2.252	0.102
Lycaena phlaeas	Catalonia BMS	19.23 (912.95)	2.464	0.134
Maniola jurtina	Catalonia BMS	116.7 (36415.8)	2.786	0.123
Ochlodes sylvanus	Catalonia BMS	13.6 (1473.35)	3.633	0.092
Pararge aegeria	Catalonia BMS	117.5 (32063.96)	3.807	0.073
Pieris brassicae	Catalonia BMS	40.92 (3556.65)	2.081	0.087
Pieris napi	Catalonia BMS	33.11 (7785.15)	3.868	0.123
Pieris rapae	Catalonia BMS	119.8 (24977.56)	2.217	0.067
Polyommatus icarus	Catalonia BMS	81.77 (16308.69)	2.985	0.148
Pyronia tithonus	Catalonia BMS	46.71 (16168.38)	9.794	0.198
Aphantopus hyperantus	Finland BMS	327.35 (144759.77)	3.922	0.102

Species	Scheme	Typical initial annual count per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Argynnis aglaja	Finland BMS	17.75 (666.4)	2.058	0.200
Ochlodes sylvanus	Finland BMS	20.92 (1207.91)	6.277	0.373
Pieris brassicae	Finland BMS	1.35 (31.56)	3.053	0.615
Pieris napi	Finland BMS	121.3 (59615.41)	5.615	0.388
Polyommatus icarus	Finland BMS	8.33 (779.25)	3.969	0.692
Thymelicus lineola	Finland BMS	86.58 (22343.45)	5.116	0.138
Aglais io	Netherlands BMS	7.73 (310.18)	7.89	0.16
Aglais urticae	Netherlands BMS	7.58 (428.88)	4.04	0.11
Anthocharis cardamines	Netherlands BMS	2.83 (204.45)	14.15	0.46
Aphantopus hyperantus	Netherlands BMS	42.8 (42806.86)	12.95	0.36
Argynnis paphia	Netherlands BMS	0.06 (1.2)	5.60	1.49
Callophrys rubi	Netherlands BMS	1.3 (98.77)	10.82	0.18
Celastrina argiolus	Netherlands BMS	4.43 (145.47)	3.37	0.15
Coenonympha pamphilus	Netherlands BMS	30.35 (3920.34)	4.94	0.17
Gonepteryx rhamni	Netherlands BMS	12.85 (1185.1)	5.03	0.11
Lycaena phlaeas	Netherlands BMS	9.77 (717.75)	8.45	0.18
Maniola jurtina	Netherlands BMS	129.8 (79033.08)	4.49	0.13
Ochlodes sylvanus	Netherlands BMS	16.28 (3371.09)	4.61	0.19
Pararge aegeria	Netherlands BMS	34.89 (4763.98)	4.82	0.14
Pieris brassicae	Netherlands BMS	7.81 (263.62)	2.63	0.16
Pieris napi	Netherlands BMS	48.31 (9154.66)	4.43	0.16
Pieris rapae	Netherlands BMS	45.43 (4253.81)	4.40	0.10
Polyommatus icarus	Netherlands BMS	28.33 (6821.48)	3.83	0.18
Pyronia tithonus	Netherlands BMS	14.28 (3292)	12.98	0.18
Thymelicus lineola	Netherlands BMS	18.33 (6564.49)	4.49	0.22
Aglais urticae	Ireland BMS	34.78 (3393.47)	4.66	0.29
Aphantopus hyperantus	Ireland BMS	59.55 (13564.19)	12.82	0.17
Argynnis paphia	Ireland BMS	14.87 (1185.34)	6.19	0.22
Celastrina argiolus	Ireland BMS	4.59 (155.73)	3.72	0.21
Coenonympha pamphilus	Ireland BMS	13.18 (1175.46)	7.25	0.32
Lycaena phlaeas	Ireland BMS	2.58 (28.42)	2.56	0.38
Maniola jurtina	Ireland BMS	135.9 (122921.62)	4.17	0.12
Pararge aegeria	Ireland BMS	90.81 (15514.83)	5.43	0.12
Pieris brassicae	Ireland BMS	19.85 (4531.3)	3.64	0.21
Pieris napi	Ireland BMS	80.29 (27447.12)	3.64	0.18
Pieris rapae	Ireland BMS	47.07 (11018.38)	3.14	0.26
Polyommatus icarus	Ireland BMS	16.04 (1101.01)	3.86	0.26
Aglais io	UK BMS	29.86 (2427.25)	4.011	0.103

Species	Scheme	Typical initial annual count per site (mean and variance)	Estimated variability (Standard Deviation)	
			Intercept	Slope
Aglais urticae	UK BMS	17.67 (1619.18)	3.020	0.125
Anthocharis cardamines	UK BMS	10.15 (337.98)	4.231	0.100
Aphantopus hyperantus	UK BMS	124.8 (37592.35)	4.904	0.231
Argynnis aglaja	UK BMS	8.54 (1653.51)	7.376	0.253
Argynnis paphia	UK BMS	14.87 (2525.43)	5.676	0.236
Boloria euphrosyne	UK BMS	1.05 (91.97)	11.687	0.234
Callophrys rubi	UK BMS	3.63 (2080.82)	6.973	0.229
Celastrina argiolus	UK BMS	5.05 (313.14)	2.541	0.166
Coenonympha pamphilus	UK BMS	50.12 (16527.63)	4.358	0.235
Gonepteryx rhamni	UK BMS	30.37 (3671.88)	3.887	0.088
Lycaena phlaeas	UK BMS	11.3 (2093.08)	3.033	0.208
Maniola jurtina	UK BMS	389.43 (680746.11)	3.910	0.110
Ochlodes sylvanus	UK BMS	22.48 (1985.48)	3.103	0.163
Pararge aegeria	UK BMS	65.69 (8825.21)	4.346	0.110
Pieris brassicae	UK BMS	34.29 (2575.52)	2.671	0.102
Pieris napi	UK BMS	49.47 (7226.36)	2.930	0.120
Pieris rapae	UK BMS	51.39 (7931.78)	2.883	0.126
Polyommatus icarus	UK BMS	71.55 (25725.02)	3.436	0.201
Pyronia tithonus	UK BMS	98.85 (32519)	5.291	0.441
Thymelicus lineola	UK BMS	2.24 (234.43)	4.746	0.137

As this database is already largely complete in some northern European countries the costs presented here may overestimate total costs where this data is already available. In line with the main report summary, we assume that site distribution follows Model 2a (section 5.5.2.2).

Based on this analysis, the addition of moths to the core scheme would cost between 0 to 4% extra. We therefore strongly recommend the inclusion of this module, as it is a cost-effective method to increase the number of monitored species, and the only way to include nocturnal pollinators. However, there may be considerable challenges in the availability of suitable experts and the development of relevant technologies may be hampered by the lack of suitable keys in some countries (see Chapter 7).

Table 5.3a. The costs of including the moth recording scheme per country.

Country	No. of sites	Costs/Site €	Total costs/country (€)	% increase in total scheme costs
Austria	45	€ 700	€ 31,486	3%
Belgium	23	€ 537	€ 12,354	0%
Bulgaria	56	€ 215	€ 12,018	2%
Croatia	34	€ 220	€ 7,473	2%
Cyprus	14	€ 413	€ 5,782	2%
Czechia	43	€ 245	€ 10,528	2%
Denmark	28	€ 918	€ 25,697	4%

Country	No. of sites	Costs/Site €	Total costs/country (€)	% increase in total scheme costs
Spain	28	€ 408	€ 11,419	2%
Estonia	150	€ 859	€ 128,923	4%
Finland	238	€ 624	€ 148,520	3%
France	159	€ 622	€ 98,945	3%
Germany	65	€ 381	€ 24,796	2%
Greece	48	€ 204	€ 9,803	2%
Hungary	39	€ 571	€ 22,254	3%
Ireland	136	€ 600	€ 81,586	3%
Italy	37	€ 287	€ 10,635	2%
Latvia	37	€ 263	€ 9,738	2%
Lithuania	12	€ 900	€ 10,798	3%
Luxembourg	10	€ 378	€ 3,780	2%
Malta	26	€ 850	€ 22,104	4%
Netherlands	141	€ 210	€ 29,645	2%
Poland	46	€ 363	€ 16,717	2%
Portugal	110	€ 239	€ 26,292	2%
Romania	30	€ 240	€ 7,192	2%
Slovakia	19	€ 446	€ 8,465	3%
Slovenia	217	€ 531	€ 115,335	3%
Sweden	197	€ 1,015	€ 199,895	5%
UK	114	€ 764	€ 87,106	3%
Total	**2,012**	**€ 561**	**€ 1,179,285**	**2%**
EU	**1,988**	**€ 549**	**€ 1,092,179**	**2%**

Appendix 5.4. Cost estimations

Table 5.4a. National contacts who supplied cost data

Country	Contact	Organisation
Belgium	Denis Michez, Nicolas Vereecken	University of Mons; ULB (Free University of Brussels)
Cyprus	Menelaos Stavrinides	Cyprus Institute of Technology
Estonia	Marika Mand	Estonian University of Life Sciences
Finland	Mikko Kuussaari	SYKE (Finnish environment Institute)
France	Adam Vanbergen; Marie-Pierre Chauzat	INRA; ANSES
Germany	Axel Hochkirch; Alexandra-Maria Klein; Ingolf Steffan-Dewenter	Trier University; University of Freiburg; University of Würzburg
Greece	Theodora Petanidou	University of the Aegean
Hungary	Aniko Kovacs-Hostyanszki	Centre for Ecological Research
Italy	Marino Quaranta	CREA (Council for Agricultural Research and Economics)
Ireland	Úna FitzPatrick	National Biodiversity Data Center

Lithuania	Giedrius Švitra	
Luxembourg	Xavier Mestdagh	Luxembourg Institute of Science and Technology
Malta	Mario Balzan	MCAST (Malta College of Arts, Science and Technology)
Netherlands	Bas Oteman, David Kleijn	De Vlinderstichting; Wageningen University
Poland	Hajnalka Szentgyorgyi	Jagiellonian University
Portugal	Eva Monteiro	University of Lisbon
Romania	Albert Scrieciu	National Institute for Research and Development of Marine Geology and Geoecology
Spain	Nacho Bartomeus; Jordi Bosch	EBD-CSIC (Doñana Biological Station); CREAF (Ecological and Forestry Applications Research Center)
Sweden	Karin Ahrné, Lars Petterson	Swedish University of Agricultural Sciences; Lund University
UK	Claire Carvell, Tom Breeze	UKCEH, University of Reading

Table 5.4b. – countries used to generate proxy costs for countries with no primary data supplied; * for Luxembourg, proxies were only used for ID staff costs and fuel costs.

Country	**Average constructed from**
Austria	Germany, France, Netherlands
Bulgaria	Romania, Hungary, Poland
Croatia	Romania, Hungary, Poland
Czechia	Romania, Poland, Lithuania
Denmark	Sweden, Finland, Netherlands
Latvia	Estonia, Lithuania, Poland
Luxembourg*	Belgium, Netherlands, Germany
Slovakia	Romania, Poland, Lithuania
Slovenia	Spain, Cyprus, Greece

Table 5.4c. – Currency exchange rates (2019 annual average) drawn from the European Central Bank

Currency	**Local currency/€**
Swedish Kroner (SEK)	10.5891
British pound (GBP)	0.87777
Romanian Lel (ROM)	4.7453
Polish Zloty (PLN)	4.2976
Hungarian forint (HUF)	325.3
Czech Koruna (CZK)	25.670
Danish Kroner (DKK)	7.4661
Bulgarian lev (BGN)	1.9558
Croatian Kuna (HRK)	7.4180

Cost Assumptions

A number of assumptions were used to generate the scheme-wide cost estimates, most of which can be varied within the cost calculator spreadsheet (section 4). These assumptions are as follows:

- *Staff numbers*: each professional will manage 5 sites while volunteers will only manage 1 each.
- *Methods employed*: only pan traps (10 triplets per site) and transect walks (4 transects per site) are used.
- *Travel time*: travelling to sites is an average of a 120 km round trip (i.e. 60 km there and 60 km back) and staff travel at 60 km/hr. If pan traps or light traps are used then this will require 2 trips, one to place the traps and another to collect them.
- *Fuel*: volunteers are not paid for their time in travelling to sites but are still able to claim fuel expenses at a standard rate.
- *Accommodation*: As pan-trap data collection occurs over 24hrs, it is likely that recorders will have to stay overnight during each field visit. As such, an extra €50/visit/site is added to the costs. These costs are very likely to vary between countries and may be unnecessary if the sites are within close proximity to the recorder's base institution/home.
- *Processing time*: in addition to the time spent collecting specimens, staff will spend time processing samples (placing specimens into tubes, labelling them as best they can and entering data). This will take up 2hrs per round if pan traps are used (Breeze et al., 2020) or 1hr if only transects are used.
- *Identification*: all specimens are identified in the country they were sampled in and take an average of 5 mins (0.09hrs) each to either verify or fully identify. Note that the specimens collected are based on two times the UK estimates from Carvel et al., 2016 and may over or underestimate catches in countries with lower or greater pollinator abundance and diversity.
- *Storage*: all collected specimens will be stored in Eppendorfs at the identifiers' host organisation. These cost €0.14/specimen (Breeze et al., 2020) based on an average cost of Eppendorfs of varying sizes.
- *Sample postage*: recorders post specimens from all sites that they manage every sampling round. By default, this means volunteers will post 1 sites worth of specimens and professionals 5 sites worth of specimens, once per sample round to minimise the risks of sample decay. Additionally, if ID is local, one professional is assumed to be based at an institute where specimen ID will take place and thus has no postage costs.
- *Volunteer postage*: Materials are posted at a rate of 1/V where V is volunteer retention. We have assumed that, on average, volunteers will stay involved for 2 years, meaning that 50% of the sampling materials need to be posted annually.
- *Training costs*: every year training events are held for up to 20 participating staff at a time in each participating country, led by one identifier. Professional field staff and ID staff are paid for their time as normal. These workshops are assumed to involve an average 200 km round trip per staff member, with fuel paid for.
- *5yr postage:* every 5 years, there is an initial send out of materials to each professional recorder.
- *Administration:* the scheme is administered centrally in Belgium with 1 member of staff per 250 sites (8 staff by default). This is assumed to have organisational overheads equal to 150% of the staff salary.

Instructions for cost calculator

In order to operationalise the collected data, we developed an Excel-based cost calculator in which all cost scenarios in section 4 were itemised. This allows users to explore different scheme structures and variables. It contains the following tabs:

- Materials: The material costs presented in Tables 5.13, 5.15 and 5.17 of Chapter 5
- Time: The time costs presented in Tables 5.14, 5.16 and 5.18 of Chapter 5
- Sampling: The samples per method from Table 5.19 of Chapter 5

- Fuel: the national costs/km for fuel supplied by correspondence in Table 5.3a Cells in green are proxy values based on Table 5.4a.
- Postage costs: the costs of posting specimens within each country and between each country and Germany, derived from DHL and TNT. Links and sample addresses are provided within the tab. All costs were collected between 20–22/02/20 and may have changed since.
- Land Area: Computes site distribution following distribution Model 2 (10 fixed), as well as alternative distributions based on no fixed sites (true distribution) and 1, 5, 20 and 25% fixed per country.
- Capacity: Computes site distribution following distribution Models 3 and 4
- Costings (Full): Calculates the costs of the scheme, following the assumptions entered in the output tab
- Output: this tab summarises the costs of the 5 different distribution models and allows users to control the following parameters in Column B:
    - Sites (pre rounding): the approximate number of sites within the network (Default: 2100)
    - Years: the number of years for which the cost projections are to be made (Default: 10)
    - Sampling rounds: the number of sampling rounds per year (Default: 8)
    - Distance to Site (km round trip): the average round trip (there and back) distance between sites. (Default: 120 km)
    - Travel rate: the distance per hour that recorders are assumed to travel at (Default: 60 km)
    - Pan Traps: A yes/no variable that adds or removes pan traps from the network (Default: yes)
    - Pan traps/site: The number of pan trap stations (3 traps per station) per site (Default: 10)
    - Overnight Sampling: A yes/no variable that adds/removes the assumption that pan traps are kept out for 24hrs and the costs associated with this: additional travel to sites and overnight accommodation. (Default: Yes)
    - Transects: A yes/no variable that adds or removes transect walks from the network (Default: yes)
    - Lethal transects: a yes/no variable that adds or removed lethal sampling of specimens (and the subsequent ID costs) from the transects (Default: Yes)
    - Transects/site: The number of transects per site (Default: 4)
    - Light traps: A yes/no variable that adds or removes light traps from the network (Default: no)
    - Light traps/site: The number of light traps per site (Default: 5)
    - Paid accommodation: A yes/no variable that assumes the scheme does/does not pay for overnight accommodation if overnight sampling is required (Default: Yes)
    - % professionals: The % of sites to be sampled by professionals (Default: 50%)
    - % volunteers: the % of sites to be sampled by volunteers (Default: 50%)
    - Sites/pro: the number of sites each professional recorder is expected to manage. The number of professionals employed is based on the total sites per country divided by this number rounded down (Default: 5).
    - Sites/volunteers: the number of sites each volunteer recorder is expected to manage (Default: 1).

- Av. Volunteer years: the average number of years a volunteer is expected to remain in the scheme. This affects costs related to posting materials to volunteers and the number of volunteers requiring bespoke training each year (if that option is enabled). (Default: 2)

- Staff/training event: the maximum number of staff expected to attend each training event (default: 30)

- Training Travel: the average round trip (there and back) distance required to attend training events. (Default: 200 km)

- Years between training: the number of years separating each training event. Note that training costs are calculated as an annual average at a rate of 1/ this number. (default: 1)

- Bespoke Volunteer Training: a yes/no variable – if switched to yes, this assumes that each volunteer is given one-to-one training in the same manner as the UK pollinator Monitoring Scheme (UKPOMS) where an experienced professional researcher (ID Staff) visits the volunteer and spends one day training them. This adds an annual cost based on the number of volunteers expected to be trained each year (based on the Av volunteer years) and a one-off initial cost where all other volunteers are trained. (Default: no)

- Bespoke training distance (km): the distance that professional researchers are expected to travel to each volunteer (round trip) receiving bespoke training. (default: 120 km)

- Identification: determines if Identification is local or central – i.e. handled in a particular country (note: this is not fully operation in v1.3. and only updates postage costs, not ID time). (Default: local)

- Administration: has one of three settings (Default: Central):

- Central – where administration of the scheme is handled by a single authority in one country

- Regional – where administration is handled in four regional hubs, one for each of North Europe, Western Europe, Eastern Europe and Southern Europe.

- Local: where each country has a single dedicated administrator

- Central: controls the location for the central administration is set to Central (Default: Bel)

- Regional: North/East/South/West: Each controls the location of the regional administration hubs (Default: Sweden/Poland/Greece/Netherlands – based on capacity and reliable cost data).

- Sites/administrator: The number of sites each administrator is expected to manage, a proxy for the number of administrators (Default:250)

- Total administrators: an automatic variable that is Sites divided by sites/administrator (Default:8)

- Administrators/region: the number of administrators per region (total administrators/region) based on Sites divided by sites/administrator divided by four (Default: 2)

- Include UK: a yes/no variable that includes or removes the UK from any potential monitoring scheme. This will recalculate both the costs and the number of sites involved in each distribution model (Default: Yes).

- EU Only Summary: A yes/no variable that includes or removes the UK costs from the total costs presented in the output tab. Note that the UK is still assumed to incur costs; they are simply not displayed.

- Custom Site Distribution – these cells allow users to set the number of sites and regularity of sampling for each country independently. Please note that a minimum of 1 site must be selected for each country except the UK. The UK can only have 0 sites if “Include UK” is set to “No” – otherwise Div/0! Errors will be returned.

A copy of the cost calculator can be obtained from Dr Tom Breeze (t.d.breeze@reading.ac.uk)

Appendix 5.5. Alternative Scheme Network costs

The costs of alternative site network distributions with larger numbers of sites to generate greater detection power (following section 5.1.3.) were calculated by altering the base number of sites in the cost calculator. The resultant number of sites and associated costs per country and at an EU level are presented below.

Table 5.5a. summary of scheme costs in each Member State with 2,500 base sites, using model 2 distribution (section 5.5.2.3)

Country	Sites	Establishment costs	Annual costs	Total costs (10 years)
Austria	52	€ 6,958	€ 398,158	€ 3,988,538
Belgium*	26	€ 3,592	€ 196,385	€ 1,967,443
Bulgaria	66	€ 8,799	€ 208,252	€ 2,091,323
Croatia	39	€ 5,356	€ 124,519	€ 1,250,542
Cyprus	14	€ 1,821	€ 69,075	€ 692,568
Czechia	50	€ 6,832	€ 185,244	€ 1,859,273
Denmark	32	€ 4,442	€ 259,573	€ 2,600,177
Estonia	32	€ 4,299	€ 154,823	€ 1,552,524
Finland	181	€ 24,935	€ 1,436,239	€ 14,387,328
France	288	€ 39,217	€ 2,171,280	€ 21,752,020
Germany	192	€ 26,382	€ 1,349,702	€ 13,523,399
Greece	77	€ 10,514	€ 343,474	€ 3,445,250
Hungary	57	€ 7,646	€ 204,239	€ 2,050,038
Ireland	46	€ 6,334	€ 306,297	€ 3,069,303
Italy	163	€ 22,074	€ 1,046,047	€ 10,482,543
Latvia	43	€ 5,810	€ 187,129	€ 1,877,100
Lithuania	43	€ 5,777	€ 221,352	€ 2,219,294
Luxembourg	12	€ 1,577	€ 100,490	€ 1,006,474
Malta	10	€ 1,329	€ 53,308	€ 534,412
Netherlands	30	€ 4,093	€ 252,534	€ 2,529,430
Poland	170	€ 22,611	€ 516,885	€ 5,191,465
Portugal	54	€ 7,203	€ 288,020	€ 2,887,404
Romania	132	€ 17,461	€ 374,961	€ 3,767,067
Slovakia	34	€ 4,482	€ 125,013	€ 1,254,609
Slovenia	21	€ 2,850	€ 106,167	€ 1,064,520
Spain	263	€ 35,328	€ 1,579,140	€ 15,826,731
Sweden	239	€ 34,624	€ 1,886,782	€ 18,902,440
UK**	137	€ 18,435	€ 1,202,343	€ 12,041,865
Total	**2,505**	**€ 340,783**	**€ 15,347,430**	**€ 170,917,217**
Total EU	**2,368**	**€ 322,347**	**€ 14,145,087**	**€ 158,875,352**

Table 5.5b. summary of scheme costs in each Member State with 3,000 base sites, using model 2 distribution (section 5.5.2.3.)

Country	Sites	Establishment costs	Annual costs	Total costs (10 years)
Austria	62	€ 8,303	€ 474,662	€ 4,754,922
Belgium*	29	€ 3,998	€ 218,908	€ 2,193,073

Country	Sites	Establishment costs	Annual costs	Total costs (10 years)
Bulgaria	78	€ 10,377	€ 246,074	€ 2,471,120
Croatia	45	€ 6,235	€ 143,700	€ 1,443,233
Cyprus	15	€ 2,096	€ 73,984	€ 741,938
Czechia	59	€ 8,119	€ 218,651	€ 2,194,629
Denmark	37	€ 5,286	€ 300,417	€ 3,009,452
Estonia	37	€ 5,072	€ 179,143	€ 1,796,501
Finland	219	€ 30,202	€ 1,737,786	€ 17,408,067
France	350	€ 47,637	€ 2,638,534	€ 26,432,981
Germany	233	€ 32,051	€ 1,637,900	€ 16,411,054
Greece	92	€ 12,464	€ 410,149	€ 4,113,958
Hungary	67	€ 8,980	€ 240,038	€ 2,409,358
Ireland	54	€ 7,329	€ 358,748	€ 3,594,808
Italy	198	€ 26,842	€ 1,270,711	€ 12,733,949
Latvia	51	€ 6,921	€ 221,707	€ 2,223,995
Lithuania	51	€ 6,876	€ 262,171	€ 2,628,591
Luxembourg	13	€ 1,735	€ 108,240	€ 1,084,138
Malta	10	€ 1,329	€ 53,308	€ 534,412
Netherlands	34	€ 4,590	€ 285,894	€ 2,863,528
Poland	206	€ 27,436	€ 626,371	€ 6,291,141
Portugal	64	€ 8,547	€ 341,326	€ 3,421,810
Romania	160	€ 21,187	€ 454,508	€ 4,566,271
Slovakia	40	€ 5,317	€ 147,080	€ 1,476,118
Slovenia	24	€ 3,190	€ 121,101	€ 1,214,199
Spain	320	€ 42,986	€ 1,921,374	€ 19,256,726
Sweden	290	€ 41,975	€ 2,289,146	€ 22,933,433
UK**	165	€ 22,211	€ 1,448,018	€ 14,502,389
Total	**3,004**	**€ 409,293**	**€ 18,429,650**	**€ 205,228,358**
Total EU	**2,839**	**€ 387,083**	**€ 16,981,632**	**€ 190,725,970**

Table 5.5c. summary of differences in 10 year costs in each Member State with 2,100, 2,500 and 3,000 base sites, using model 2 distribution (section 5.5.2.3.)

Country	Difference in total Sites		Difference in Total costs (10 years)	
	2500 site network	3000 site network	2500 site network	3000 site network
Austria	7	17	€ 528,705	€ 1,295,089
Belgium*	3	6	€ 222,738	€ 448,368
Bulgaria	10	22	€ 316,675	€ 696,472
Croatia	5	11	€ 161,436	€ 354,127
Cyprus	0	1	€ 0	€ 49,370
Czechia	7	16	€ 258,549	€ 593,905
Denmark	4	9	€ 321,943	€ 731,218

Country	Difference in total Sites		Difference in Total costs (10 years)	
	2500 site network	3000 site network	2500 site network	3000 site network
Estonia	4	9	€ 192,594	€ 436,571
Finland	31	69	€ 2,463,822	€ 5,484,561
France	50	112	€ 3,775,572	€ 8,456,533
Germany	33	74	€ 2,322,002	€ 5,209,657
Greece	12	27	€ 535,986	€ 1,204,694
Hungary	9	19	€ 322,294	€ 681,614
Ireland	7	15	€ 466,034	€ 991,539
Italy	27	62	€ 1,734,144	€ 3,985,550
Latvia	6	14	€ 260,233	€ 607,128
Lithuania	6	14	€ 307,839	€ 717,136
Luxembourg	0	1	€ 0	€ 77,664
Malta	0	0	€ 0	€ 0
Netherlands	4	8	€ 334,097	€ 668,195
Poland	29	65	€ 885,228	€ 1,984,904
Portugal	8	18	€ 422,753	€ 957,159
Romania	22	50	€ 627,590	€ 1,426,794
Slovakia	4	10	€ 146,817	€ 368,326
Slovenia	2	5	€ 100,196	€ 249,875
Spain	46	103	€ 2,766,076	€ 6,196,071
Sweden	42	93	€ 3,319,814	€ 7,350,807
UK**	23	51	€ 2,024,170	€ 4,484,694
Total	**403**	**902**	**€ 27,553,652**	**€ 61,864,793**
Total EU	**382**	**853**	**€ 25,529,482**	**€ 57,380,100**

Table 5.5d. Costs sensitivity matrix for schemes lasting 5, 7 or 10 years with variables numbers of sites, sampling rounds under both site distribution models (Section 5.5.3.2). All costs presented in €M for the EU only (the UK is included in the network but not the total costs).

Years	Rounds	Model 2: Area only (€M)			Model 3: Area and Species (€M)		
		2100 sites	2500 sites	3000 sites	2100 sites	2500 sites	3000 sites
10	10	€ 162.4	€ 193.5	€ 232.3	€ 158.7	€ 189.1	€ 226.8
10	8	€ 133.3	€ 158.9	€ 190.7	€ 130.4	€ 155.3	€ 186.3
10	6	€ 104.3	€ 124.3	€ 149.2	€ 102.1	€ 121.6	€ 145.8
10	4	€ 75.3	€ 89.6	€ 107.6	€ 73.7	€ 88.7	€ 105.3
7	10	€ 113.8	€ 135.5	€ 162.7	€ 111.2	€ 132.5	€ 158.9
7	8	€ 93.4	€ 111.3	€ 133.6	€ 91.4	€ 108.8	€ 130.5
7	6	€ 73.1	€ 87.1	€ 104.5	€ 71.5	€ 85.2	€ 102.2
7	4	€ 52.8	€ 62.8	€ 75.4	€ 51.7	€ 61.6	€ 73.8
5	10	€ 81.3	€ 96.9	€ 116.3	€ 79.5	€ 111.2	€ 158.7
5	8	€ 66.8	€ 79.6	€ 95.5	€ 65.3	€ 91.4	€ 130.4
5	6	€ 52.3	€ 62.2	€ 74.7	€ 51.1	€ 71.5	€ 102.1
5	4	€ 37.7	€ 44.9	€ 53.9	€ 37.0	€ 44.0	€ 73.7

6 General and CAP Pollinator Indicators for the EU Pollinator Monitoring Scheme

This chapter presents options for both a general pollinator indicator (section 6.1) and for a Common Agricultural Policy specific indicator (section 6.2). First we describe a general framework for indicator development based on the well-established DPSIR (*Driver-Pressure-State-Impact-Response*) framework (section 6.1.1). We then present options for State, Impact, Pressure and Response indicators (sections 6.1.2–6.1.5). The policy context for a CAP indicator is presented in section 6.2.1 followed by a roadmap for developing such an indicator (section 6.2.2), and options for a CAP impact indicator (section 6.2.3).

6.1 General pollinator indicators

The decline in the occurrence and diversity of European wild insect pollinators, including wild bees, hoverflies, butterflies and moths, is caused notably by land-use change, intensive agricultural management, pesticide use, environmental pollution, invasive alien species, pathogens and climate change (section 1.1). These pressures often operate in combination, resulting in synergetic effects on pollinators. To address these multiple pressures, calls for mitigation actions across various sectors and policies require a strategic approach at all levels of governance and the involvement of various actors. A coordinated long-term monitoring process is an essential part of this strategic approach in order to: (i) fill knowledge gaps on the status and trends of pollinators; (ii) inform about the trends of the pressure factors; (iii) assess the impacts of various EU and Member State policies, including progress towards the UN Sustainable Development Goals 2 ('Zero hunger') and 15 ('Life on land'); (iv) assess the impacts (positive and negative) of mitigation actions taken, in particular within the Common Agricultural Policy (CAP); (v) evaluate the impacts of the decline of pollinators on society and the economy; and (vi) raise awareness across society regarding the importance of pollinators and the urgent need to take action.

This section aims to provide a framework for the development and use of indicators for general surveillance monitoring (section 1.2.1) of trends of pollinator diversity, abundance and community composition as well as on pollination as an ecosystem service in the EU and its respective Member States. The proposed indicators, and their sub-components, should be available firstly at the national level of a Member State, and then, through combining the national results, should also be made available at a sub-national and EU level in order to inform policy makers.

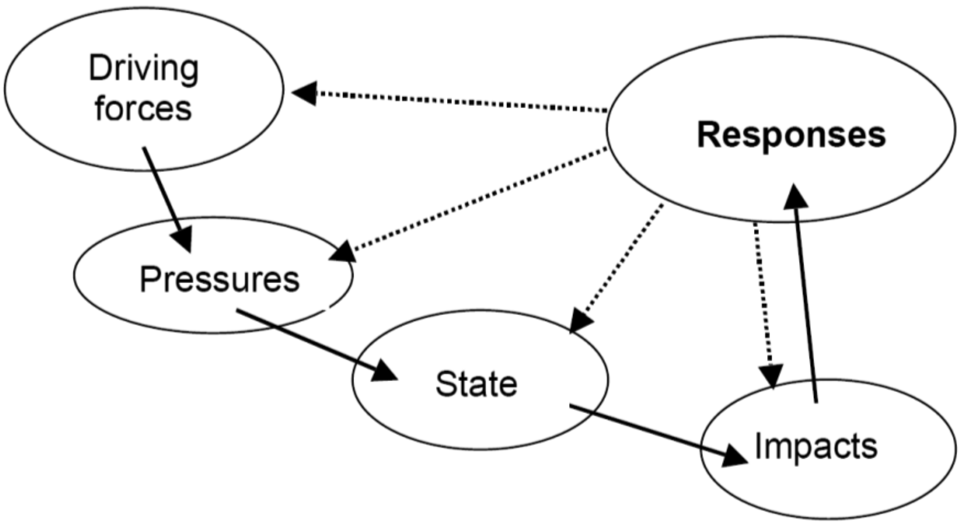
6.1.1 Developing a general framework for pollinator indicators

An existing and well-established framework for developing sets of indicators for a coordinated long-term monitoring process, such as the EU-PoMS, is the DPSIR scheme (EEA 1999; Figure 6.1). The abbreviation DPSIR stands for Drivers, Pressures, State, Impacts and Responses. DPSIR is "a conceptual framework for the description of the environmental problems


Pararge xiphioides, Axel Hochkirch

and of their relationships with the socio-economic domain, in a policy meaningful way" (Maxim et al. 2009). Social, environmental and economic developments (*Drivers* or Driving Forces, D, sometimes called indirect drivers) exert *Pressures* (P, sometimes call direct drivers) on biodiversity and the environment and, as a consequence, the *State* (S) of biodiversity and the environment changes. This leads to *Impacts* (I) on ecosystems (functioning and services), human wellbeing, and society, which may elicit a societal and/or political *Responses* (R) that feeds back on Driving Forces, on Pressures, on State or on Impacts via various actions (e.g. mitigation, adaptation, conservation) (EEA 1999; Gabrielsen & Bosch 2003; Maxim et al. 2009). The main elements of the DPSIR framework readily match the IPBES conceptual framework "connecting nature and people" (e.g. Diaz et al. 2015). The DPSIR scheme has a proven appeal to policy makers for having the potential to provide the basis for better informed decision making (Spangenberg et al. 2009), facilitated by a distinction between causes and consequences which can lead to better targeted policy responses in the decision-making process; it has been applied to analyse the pathways of the decline of pollinators and associated pollination (Kuldna et al. 2009). The scheme is, however, not automatically applicable as an analytical tool of causal chains connecting drivers and pressures to the state and trends of pollinators and pollination. This is in particular true when a surveillance monitoring approach is adopted (e.g. by the EU-PoMS). Hence, in order to improve the knowledge of the causes and consequences of pollinator decline, and for reporting back on the impacts of mitigation actions taken, a combination of suitable indicators across the DPSIR categories needs developing, specifically of pressure, state and impact indicators. To date, the DPSIR framework is mainly used in a reactive manner, whereas in order for responses to be most effective they usually need to be more proactive and consider future impacts as well as responding to impacts once they occur. For the EU-PoMS indicators within a DPSIR scheme, this denotes that indicators should serve to elucidate impacts of changes expected to be of importance in the future, rather than manifesting the known impacts of past developments.

Figure 6.1. The structure of the DPSIR framework for monitoring. Solid arrows indicate direct causal links between elements; dotted arrows indicate points at which policy and management responses can act.



The EU-PoMS requires a modular indicator system comprising both indicators and methods for surveillance (passive general trend) monitoring and for question-driven monitoring (sensu Lindenmayer & Likens 2010; see sections 1.2.1 and 6.2). The surveillance monitoring of the EU-PoMS does not attempt to identify the concrete mechanisms influencing changes in the state or trends of pollinator diversity, abundance and community composition. It will allow observation of general trends of known pressures on pollinators. That, together with the trends of pollinators and changes in the functional composition of pollinator communities, can be used for deriving hypotheses and questions on the causes of shifts and interplay of those trends. The general trend monitoring of pressure indicators can probably be largely sourced from the reporting of indicators from existing mandated monitoring of environmental data (at the EU or national level) as well as from novel monitoring approaches developed in the frameworks of the LUCAS survey[1] and the European Monitoring of Biodiversity in Agricultural Landscapes (EMBAL)[2]. The state and impact indicators of pollinators and pollination, in contrast, are sourced from a specifically designed pollinator monitoring scheme (see sections 5.2).

1 https://esdac.jrc.ec.europa.eu/projects/lucas
2 https://ec.europa.eu/environment/nature/knowledge/pdf/embal_report.pdf

6.1.1.1 Indicators within the DPSIR categories

To apply the DPSIR concept to the EU-PoMS, indicators for the respective categories of DPSIR (i.e. drivers, pressures, state, impact and response) need to be developed. For both the surveillance monitoring and the CAP indicators, pressure (P-), state (S-) and impact (I-) indicators will be of particular importance. Response (R-) indicators will be useful to show the level of awareness existing within the respective Member States, and that the type and extent of mitigation and supporting actions for pollinators and pollination have been implemented. Reports of the trends monitored can therefore be used to close the feedback loop from monitoring to policy information by (potentially) elucidating which actions have resulted in trend changes (Figure 6.1). For a clearer understanding of the indicator system within DPSIR, the respective categories and their indicators are described below with respect to pollinators and pollination.

- ***Driving forces*** are changes in the social, economic and institutional systems (and/or their relationships), which trigger, directly and indirectly, pressures on pollinators and pollination (Kuldna et al. 2009). Driving forces are also sometimes referred to as indirect drivers. ***D-indicators*** describe developments at the national or sub-national scale of drivers known to directly or indirectly affect pressures, such as land-use and climate change. No new D-indicators need to be developed for EU-PoMS, as information can be sourced from existing national statistics of Member States; for example, demographic statistics, climate change and subsidisation policy etc., however being indirect drivers, they are of less relevance as indicators for pollinators and pollination than direct drivers (P-indicators).

- ***Pressures on pollinators*** are consequences of activities, which have the potential to cause or contribute to adverse effects in the diversity or abundance of pollinators (Kuldna et al. 2009). Pressures are also sometimes referred to as direct drivers. ***P-indicators*** are less coarse than D-indicators and more closely related to pollinator or pollination changes. They should comprise the known factors causing adverse effects on pollinators. In addition, because mitigation actions on known pressures are taken by any Member States, implementation of such actions should also be reported. This includes reporting on the implementation of CAP-related measures within the respective Member States. Reporting at the sub-national scale within Member States is preferable because measures taken to mitigate pressures should ideally be targeted at sub-national scales (e.g. areas differing in agricultural systems). Apart from reporting spatially explicit implementation of CAP related measures, no new indicators need to be developed for EU-PoMS because information can be sourced from existing national statistics of Member States.

- ***State*** of pollinators is the quantity of pollinators (measured within species and between species), vulnerable to pressure(s), in a given area (Kuldna et al. 2009). S-indicators correspond closely to the “presence of pollinators” category of indicators presented by Bartholomée & Lavorel (2019). S-indicators focus on pollinators and their changes over time, and are suitable for both surveillance monitoring, and question-driven monitoring related to the CAP or other international liabilities such as CBD, SDG 15 and European Biodiversity Strategy.

- ***Impacts*** are consequences of changes in the state of pollinators, in social, economic and environmental dimensions (Kuldna et al. 2009). ***I-indicators*** report on the impacts that a change in status has on ecosystems and ecosystem functions and services. Bartholomée & Lavorel (2019) present some potential options for I-indicators including pollen transfer, pollination success and harvest for human consumption (section 6.1.3.2).

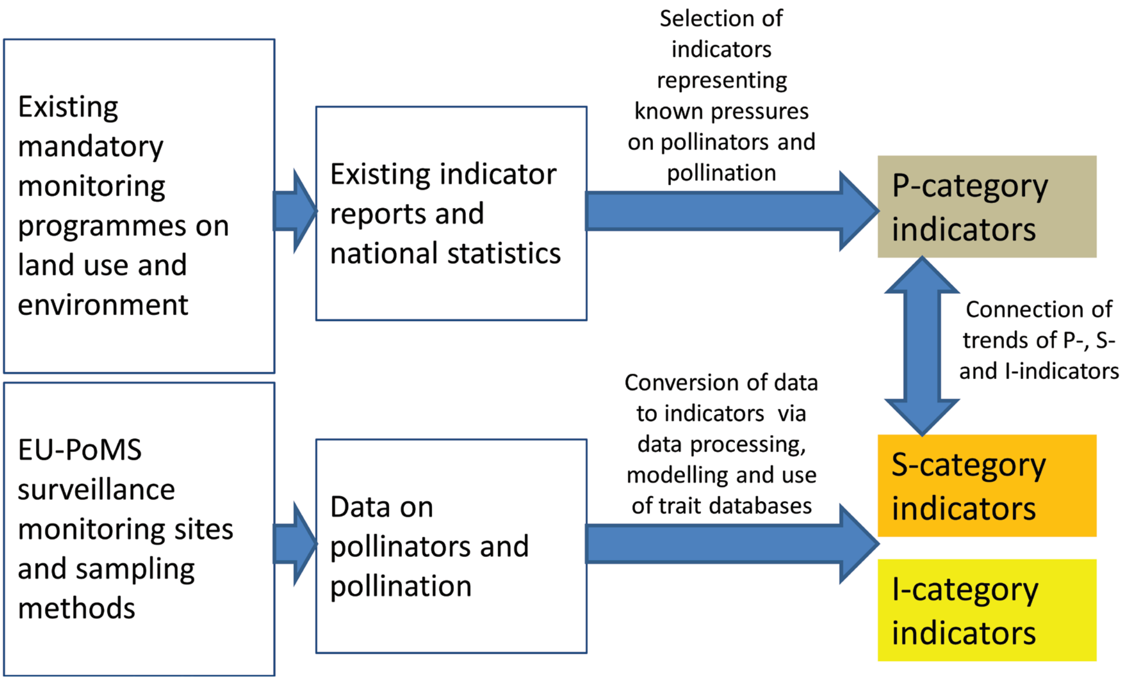
- ***Response*** is a policy or management action, initiated by institutions or groups which is directly or indirectly triggered by impacts and which attempts to prevent, eliminate, compensate, reduce or adapt to the consequences of impacts (Kuldna et al. 2009). ***R-indicators*** comprise all responses to pollinator decline and pollination limitation available in the Member States. The response could be directly designed for pollinators (e.g. a national pollinator strategy) or indirectly embedded in more general biodiversity or environmental strategies.

6.1.1.2 Development of indicators for the EU-PoMS surveillance monitoring of pollinators and pollination

Surveillance monitoring uses a range of variables in order to estimate trends or provide *ad hoc* environmental insights (Chapter 4, Nichols & Williams 2006). It is designed for the potential to detect unexpected patterns of change, the ‘unknown unknowns’ (Wintle et al. 2010), or ‘surprises’ *sensu* Hilborn (1987). It is not based on clearly stated *a priori* hypotheses and therefore it is applicable for gaining insights and informing management and policy decisions about large-scale environmental issues (e.g. land-use and climate change or pollution). In addition, surveillance monitoring provides wider benefits such as educating or engaging the public (Possingham et al. 2012). Nevertheless, the information from surveillance monitoring can be difficult to interpret if the major drivers and pressures of change are not also monitored (Reynolds et al. 2016). For example, long-term surveillance monitoring may indicate that urgent action on pollinators is needed, but it will not provide information on which action(s) would be most effective because management and measures were not incorporated into the survey design (Reynolds et al. 2016). Reports of severe trend changes from surveillance monitoring can trigger further study in the form of research to determine causes of the decline and possible mitigation actions to be taken. In this context, a conceptual framework of the system can help to guide the selection of the appropriate indicators on known pressures to be combined with unknown trends of state and impact, facilitating the interpretation of the trend changes and providing feedback about the efficiency or responses.

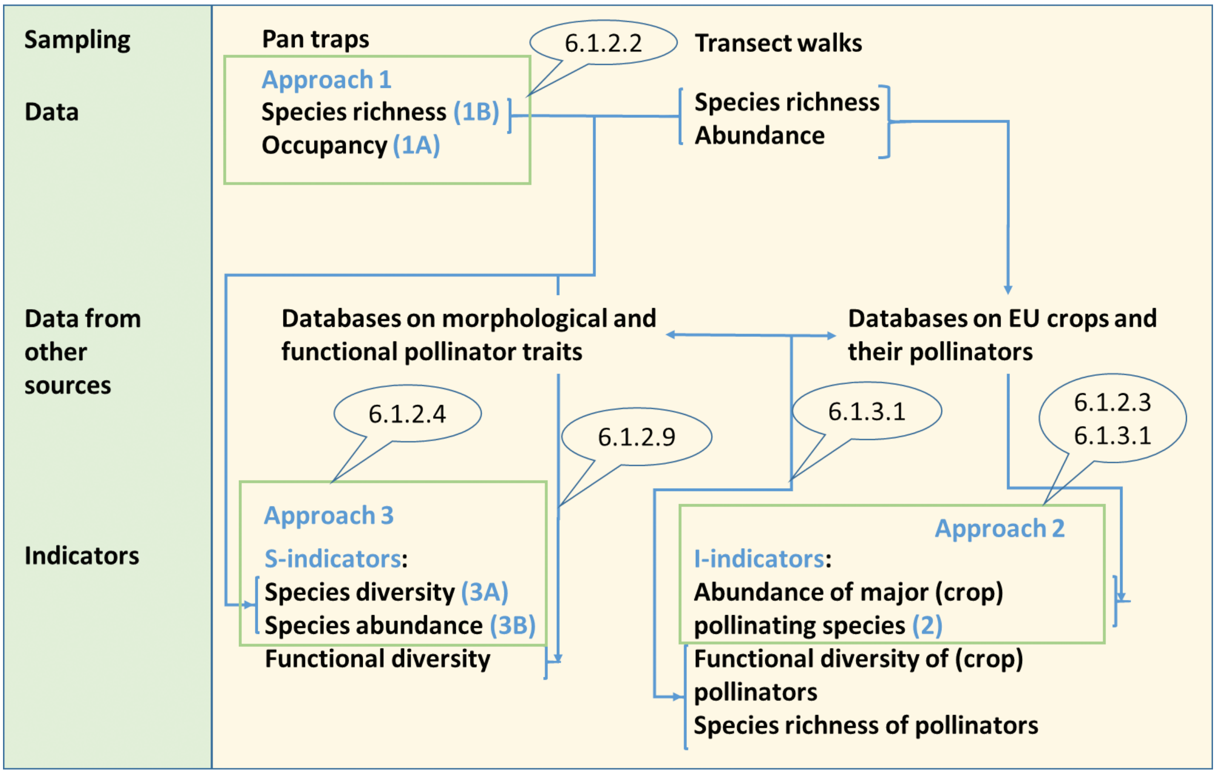
The scheme presented in Figure 6.2 shows the general conceptual framework for the construction and interplay of P-, S-, and I-indicators for the EU-PoMS surveillance monitoring. Informed by the known pressures on pollinators and pollination (IPBES 2016), relevant P-indicators can be selected. Their trends in time and where possible in space (e.g. sub-national differentiated trends within Members States) may be derived from already existing mandatory monitoring programmes. In contrast, S- and I-indicators, require a EU-PoMS specific construction, informed by the decisions taken on sampling design, sampling methods and choice of target taxa. This selection and construction of the respective indicators is described in the following sub-sections.

Figure 6.2. Development of indicators and their interplay in the EU-PoMS surveillance monitoring.



Within the DPSIR framework applied to the EU-PoMS, in particular the S- and I-category indicators are of highest importance. Their nature, quality and indication potential strongly depend on the selection of the monitoring sites, the methods of species sampling applied and the taxonomic resolution of the taxa sampled. Of further importance is the quality and availability of species-specific information on morphological and functional traits of pollinators. These aspects of the EU-PoMS are described in Chapters 4 (methods) and 5 (scheme design). Based on the recommendations for a Minimum Viable Scheme (MVS, section 5.2) and data processing, a framework for the construction of S- and I-indicators was developed (Figure 6.3). The highest level of quality of the S-indicators can be reached when specimens of both pan trap and transect walk samples are identified to species level for the respective groups of pollinators. In this case, the construction of the S-indicators can follow the approaches 3A and 3B described in the section 6.1.2 (Construction of State-indicators, see also Table 6.1). Species abundance information from the transect walk data is also important for the construction of the I-indicator (approach 2 in Table 6.1, section 6.1.3). For this, the respective species lists will be screened in conjunction with trait and crop databases to identify the occurrence of crop pollinating species in the monitoring sites (Figure 6.3). The functional diversity and abundances of those species can serve as a proxy for pollination services. In the case where there is no species-level information from the transect walks, and hence no abundance data available for some pollinator groups, the species data from the pan trapping can still serve to inform an S-indicator for trends in species richness and occupancy (approaches 1A and 1B in Table 6.1). An I-indicator derived from pan trap data is usable but lower in quality in comparison to the I-indicator derived from approach 2 (Table 6.1), because abundance of crop pollinators has been shown to have a strong indicative potential for pollination services (Winfree et al. 2015).

Figure 6.3. Scheme of the construction of S- and I-indicators for the general surveillance monitoring of pollinators (text in blue: reference to Table 6.1, balloons indicate the respective sub-chapters). The databases shown here are examples of databases which could be complemented by additional databases, e.g. on major pollinators of wild plants or rare plants to cover nature conservation aspects. For approach 1, the data on species richness (1A) and occupancy (1B) resemble the indicators, whereas approach 2 and 3 require some data processing for the construction of the respective indicators (6.1.2.3, 6.1.2.4).



6.1.2 Options for state indicators

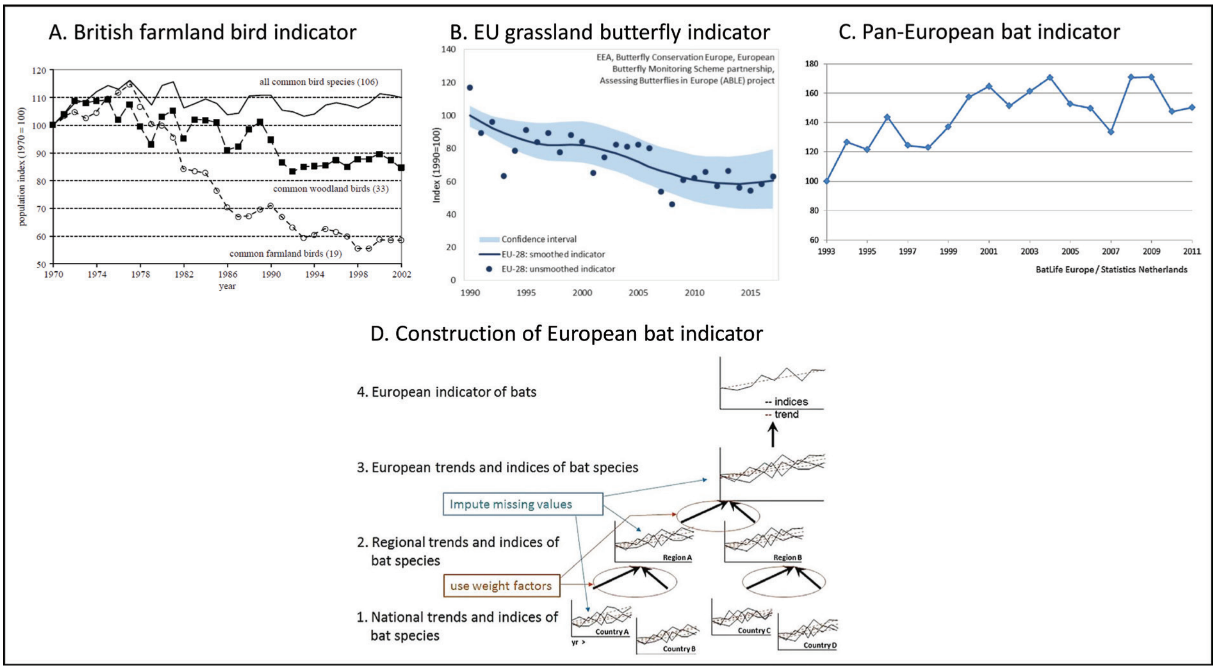
The pollinator state indicators will be based on empirical pollinator measures that will be annually provided by the national pollinator monitoring schemes. These measures are the abundance and species richness of bumble bees, solitary bees, hoverflies and butterflies (and also, potentially, moths). Pan traps provide data on both occupancy and species richness, while transect walks produce estimates of species richness and abundance (see Chapter 4). From species identities, qualitative and quantitative information on community composition can be derived.

6.1.2.1 *What data will be available and what data products can be produced?*

The Minimum Viable Scheme includes a protocol combining pan traps and transect walks, with both survey types being replicated spatially and temporally within a series of 1 km^2 grid cells (section 5.2). The pan traps will deliver counts at the species level, although it is recommended that such counts be analysed as a series of presence-absence data, due to heterogeneity in attractiveness that is difficult to model. The transect walks will deliver counts, and an identification to species level (as far as possible) is highly desirable for all pollinator groups. Nevertheless, some Member States may need to develop capacity for some taxa before this high level of taxonomic resolution could be achieved (Chapter 7).

The methodology used for the existing indicators of Figure 6.4 is only applicable for species-level count data. The surveillance monitoring based on pan traps and transect walks will produce data of different qualities and taxonomic resolutions, and therefore more innovative approaches are required to integrate data from the survey types, and to address methodological biases and differences in taxonomic resolution between them.

Figure 6.4. Examples of existing European biodiversity indicators: (A) British farmland birds (Gregory et al. 2005), (B) EU grassland butterflies (Van Swaay et al. 2019) and (C) Pan-European bats (Van der Meij et al. 2015). Panel (D) illustrates the construction logic of the European bat indicator.



Given the complexity of the data and the desire for multiple, complementary, indicators (Figure 6.3), there are numerous possibilities for how the data can be analysed and converted into indicators. We propose three such approaches, which would generate a suite of indicator options (summarised in Table 6.1). Any of these approaches could be calculated for each Member State, as well as for the entire EU. The most efficient and hence recommended is approach 3 and the indicators 3A and 3B (Table 6.1).

To understand the possibilities presented by the data, it is first necessary to define some key concepts:

Study site: The sites will almost certainly be a stratified random sample of grid cells (1 km^2) within each Member State (section 5.2.3), potentially with the LUCAS sample grid given its unbiased coverage across Europe (section 5.2.2). The MVS proposes that at least 2,000 sites are implemented across Europe to assess pollinator populations (see section 5.1). There may be additional strata needed for CAP, Natura 2,000 etc. On each site there will be multiple pan trap stations and transects (i.e. several transects, one each for butterflies, bumble bees, solitary bees and hoverflies).

Sampling event: Each site will be visited on multiple occasions each year (i.e. 10 times depending upon the final method). On every visit, each pan trap will be sampled and the (taxon-specific) transect walked. The data emerging from each pan trap and from the transect walk(s) on each site are referred to as a sampling event. This definition of a sampling event is consistent with the Darwin Event Core standard, although Darwin Event Core additionally allows sampling events to be nested within one another, i.e. individual observations are nested within transect walks, which are nested with pan trap data for the same survey visit, which are nested with other visits to the same square during the field season. For the purposes of this document, we use the simpler definition.

State variable: This is the quantity to be estimated from data. In most of the models described below, the state variable is related to species' abundance.

Indicandum: The quantity or concept to be indicated. In the Farmland Bird Index and other multispecies indicators in Figure 6.4, the indicandum is the (change in) average species' abundance.

Table 6.1. Summary of suggested pollinator state indicators to measure temporal trends in pollinator diversity and abundance.

Construction approach and pollinator indicator	Sampling method(s)	Source pollinator data	Focus of the indicator	Trend detection efficiency	Advantages	Disadvantages
Approach 1: Trends in occupancy/richness						
1A: Trend in average occupancy of species	Pan traps	Presence-Absence	Pollinator diversity	Efficient	Based on a large number of species, sensitive to changes in distribution	No use of abundance data
1B: Trend in average species richness of sites	Pan traps	Presence-Absence	Pollinator diversity	Efficient	Based on a large number of species, sensitive to changes in distribution	No use of abundance data
Approach 2: Observed abundance of species groups						
2: Trend in total abundance of pollinator groups	Transects	Counts	Pollination services	Inefficient	Relevant measure of pollination services	Inefficient trend detection due to low signal-to-noise ratio (high sampling variance and interannual variation in abundance)
Approach 3: Modelled species abundance of a subset of easily-identifiable species						
3A: Trend in average species abundance	Pan traps, transects	Presence-Absence, counts	Pollinator diversity	Efficient	Efficient use of the available species-specific data	Limited to species that can be identified on transects. Difficult taxa would be excluded.
3B: Trend in average diversity of sites	Pan traps, transects	Presence-Absence, counts	Pollinator diversity	Efficient	Efficient use of the available species-specific data	May not be informative if many species cannot be identified to species level

6.1.2.2 Occupancy models from pan trap data (Option 1A and 1B)

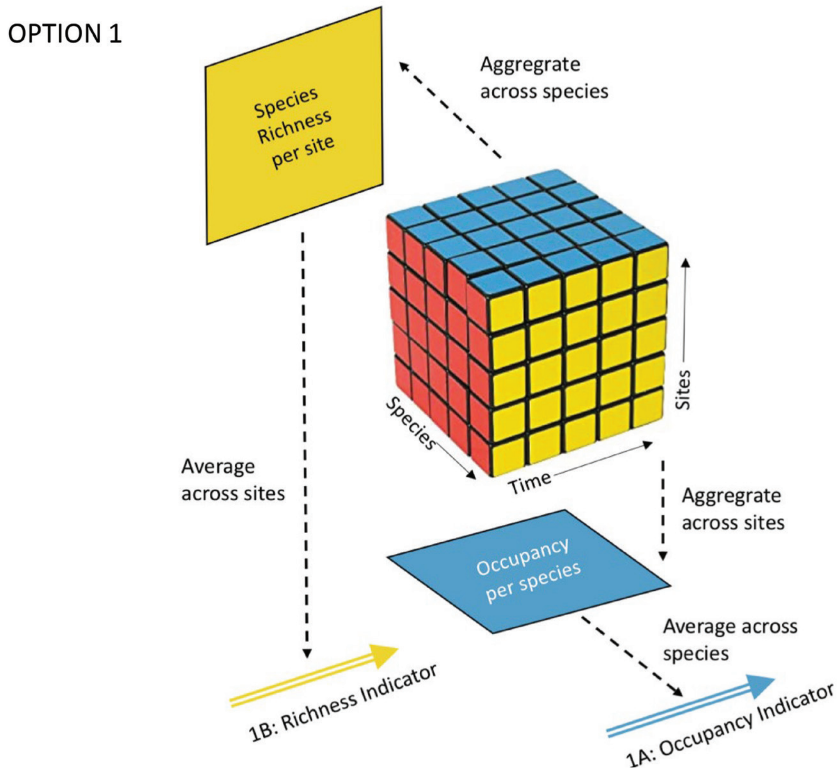
Using only the presence-absence records from the pan trap data, it is possible to estimate occupancy for each species in each site in each year. This could be done using a series of species-specific models (as in Powney et al. 2019), or using one multi-species model (as in Woodcock et al. 2016). The resulting data product is a species-site-time cube resembling an Essential Biodiversity Variable (EBV) of the species' distributions (Jetz et al. 2019; Kissling et al. 2018). Summarising across the margins of this cube would yield two possible two-dimensional datasets (Figure 6.5), from which two indicators could be easily derived:

A. Summing across sites, a table of the estimated number (or proportion) of sites occupied by each species in each year. The geometric mean *occupancy* is an alternate measure of *pollinator presence*, and consistent with how pollinator trends are currently presented in the UK, for example Powney et al. (2019).

B. Summing across species, a table of estimated species richness at each site in each year. The geometric mean *species richness* across sites could be an indicator of *pollinator presence* (*sensu* Bartholomée & Lavorel 2019).

Since these two options (1A and 1B) are different summaries of the same underlying data cube, the resulting trends should be very similar. Indeed, if species were randomly and independently distributed across study sites then they should provide identical results. However, species are not distributed in this way: e.g. there are strong latitudinal (and longitudinal) gradients in species richness. It's possible that one of these metrics is more sensitive than the other, given the unbalanced distribution of species across Europe. We recommend a series of sensitivity analyses to explore this issue in more detail.

Figure 6.5. Conceptual diagram for the derivation of indicators from occupancy modelling of species-specific pan trap data. The cells of the Rubik's cube represent individual combinations of site and species (i.e. populations) in a particular year. The data in each cell is an estimate of the probability that the site is occupied (i.e. the population is extant), derived from an occupancy model fitted to the raw data. Aggregating across sites produces a "flat" table of occupancy times-series for each species (blue plane), from which an "occupancy indicator" would be calculated as the geometric mean across species (indicator 1A, blue arrow). Summing the data cube across species produces a flat table of time-series of species richness estimates for each site (yellow plane): averaging across sites would produce an indicator of how species richness is changing on the average site (indicator 1B: yellow arrow). Uncertainty from the occupancy models to the indicators could be propagated in a straightforward manner.



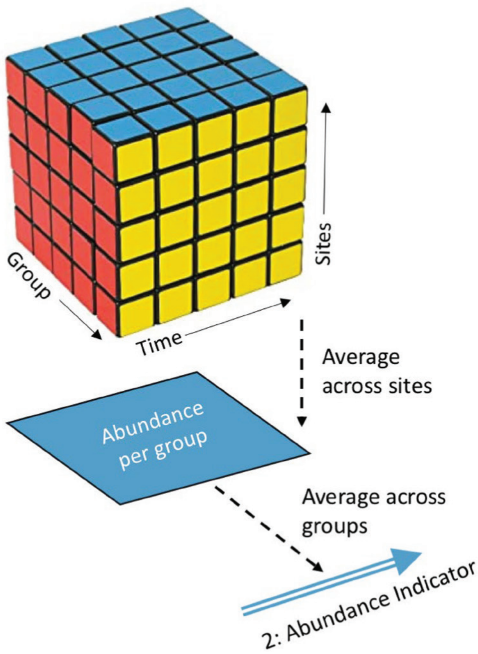
The advantage of this approach is that it would deliver species-level information for a large number of species. The two indicators described above would therefore be expected to be quite sensitive to changes in the distribution of each species (i.e. local extinctions or range expansions). The two disadvantages are (i) that the indicators would not include any information about species abundance; and (ii) this model is based solely on pan trap data, so the information contained in the transect walks would not be included in the indicator.

6.1.2.3 Total group abundance from transects (Option 2)

Transect count data could be developed into a space-time-taxon cube in which each element represents the total abundance of the taxonomic group in question (e.g. bees, or hoverflies; Figure 6.6). A simple version of this dataset could use just the counts, but it may be appropriate to account for differences in detection rates across taxa and space. For reasons previously stated, it is not appropriate to include the counts from pan traps in any measure of abundance without more fully understanding the link between landscape composition (e.g. flower density) and catch rate of pollinating insects.

Figure 6.6. Conceptual diagram for the derivation of an indicator of pollinator abundance from transect count data. The cells of the Rubik's cube represent individual combinations of site and taxonomic group (e.g. solitary bees) in a particular year. The data in each cell would modelled abundance that accounts for phenology and uneven detectability. Averaging across sites produces a "flat" table of abundance times-series for each group (blue plane), from which an "abundance indicator" would be calculated as the geometric mean across groups (blue arrow). Uncertainty from the abundance models could be propagated to the indicator in a straightforward manner.

OPTION 2



Based on this cube, it would be possible to derive two complementary summaries, each describing a trend in average *group abundance.* Given the small number of taxonomic groups and the likely high inter-annual variability in counts, it would make sense to average first across sites rather than across taxa, so only this option is presented in Figure 6.6. Although the resulting indicator would be technically a measure of *pollinator presence* rather than *pollination success* (as defined by Bartholomée & Lavorel 2019), it is more relevant to pollination services than options 1A and 1B.

The advantage of this approach is that it delivers information that is more relevant to pollination services (i.e. total abundance). The disadvantage is that total group abundance, summed across many species, is likely to contain a low signal-to-noise ratio (high sampling variance, high inter-annual variation), so a long time-series would be required for the trends to be considered robust. There is a possibility of weighting the abundance index by pollination efficiency of the respective group. For this a more extensive database of the contribution of European wild pollinators to crop pollination may be required (section 9.1.2).

This option raises some options for presentation that would need to be resolved, arising from the number of taxonomic groups for which abundance would be estimated (e.g. bumble bees, solitary bees, hoverflies and butterflies). One could: (i) combine these into a single line covering all taxonomic groups; (ii) present the four lines separately; or (iii) report the single line but include the four separate lines in the technical details.

6.1.2.4 Modelled abundance of species, integrating data from pan traps and transects (Option 3A)

This option (3A, Table 6.1) would deliver indicators similar to the Farmland Bird Indicator and others in Figure 6.4. Unlike option 2 above, this option would use the transect count data at species resolution, rather than broad groups. Observations that could not be identified to species level would therefore be excluded. The models would be more sophisticated than previous options above, in order to account for differences in sampling protocols for the two methods. Full details of the integrated model structure are given in Appendix 6.1.

This would be a state-of-the-art integrated distribution model (Isaac et al., 2020). The principal advantage is that species-specific abundance metrics could be derived, so the resultant indicators should be sensitive to change. Two additional advantages

Pieris brassicae subsp. azorensis, Adara Pardo

are that it makes the most of available data and delivers a product that resembles existing indicators such as the Farmland Bird Index and the Grassland Butterfly Index. The disadvantage of this approach is that it is restricted to the species that can be reliably and consistently identified to species level on transects. It is anticipated that the majority of observations on transects will be at species level, which makes this an attractive option. However, care will be needed to accommodate cases where species-level identification was not possible without biasing the indicator.

6.1.2.5 What if a majority of transect counts cannot be identified to species level? (Option 3B)

Based on recorder skill levels and resource constraints, a subset of observations will not be identifiable to species level on the transects. So, are there ways to derive useful information from these data, leveraging information from the species-specific data on the pan traps?

There are two ways of thinking about to how to proceed if a large proportion of the transect counts are not identified to species level.

The first, simple option, would be to analyse the data at the taxonomic resolution that is available (e.g. 'all hoverflies', 'all bumble bees'). In this case, the occupancy data from pan traps is unlikely to be informative, because it would be surprising if there were sites at which these higher-level taxa were completely absent. In this case, the model would reduce down to that described above.

A second, alternative and more complex option (option 3B), would be to assert that the total hoverfly count does tell us something about the diversity of hoverflies on the site. It would be possible to write an integrated model in which the group-level counts (from transects) and species-specific occupancy patterns (at species level) are separate realisations of some site-level state variable representing alpha diversity. The model could be specified in a way that species-level information could be used where available in modelling metrics of alpha diversity (e.g. Shannon's entropy).

If such an approach were possible, it would have the advantage of using all available data. It should therefore be highly sensitive to change in alpha diversity, but only if the diversity metric can be estimated with precision. The disadvantages are that such a model has never been attempted previously, and would present some technical and inferential challenges. There is a substantial risk that the model would be unable to estimate the parameters precisely, or that the transect counts would not, in reality, provide much information. We therefore consider this model option to be a theoretical option only, which could be developed in future, and therefore it is not included in Table 6.1.

Myathropa florea and *Bombus terrestris*, Adara Pardo

6.1.2.6 State indicator application tests

Some illustrative examples of the application of the state indicator approaches outlined (approaches 1 and 2 from Table 6.1) using real data can be seen in Appendix 6.2. These examples support the need to record the lowest taxonomic level possible, as different pollinator groups (bumble bees, solitary bees and hoverflies) show markedly different trends. Thus, recording and analysing trends for different pollinators groups separately can be essential to better understand the pressures affecting particular functional groups or specific threatened species.

6.1.2.7 Recommendations of the State Indicator

Option 3A is the most promising option, as it makes best use of available data, is sensitive to change and produces a biodiversity indicator that resembles established indicator products. However, we emphasise that the utility of Option 3A is critically dependent on delivering on the goal that the majority of species on transects are identified to species level. If, in reality, it is not practical to identify large numbers of transect observations to species-level, we recommend that Options 1, 2 and 3A be presented as complementary alternatives (Figure 6.3), since each represents a different aspect of biodiversity change. These alternative approaches would benefit from a testing phase where real data collected through a pilot EU-PoMS is developed into indicators and their effectiveness and utility assessed to help inform refinement of the approach (section 9.1.6).

6.1.2.8 National vs Continental indicators

The creation of a Europe-wide indicator would require a decision about how to weight the data from Member States. Multiple options are available, each with different strengths and weaknesses: (i) weighting all sites equally would potentially lead to misleading results at the European level, because countries with a dense monitoring network would become over-presented in the results; (ii) taking the average across Member States would disproportionately over-emphasise changes occurring in small countries; (iii) weighting the results of Member States by their land area would produce an indicator giving equal weight to all parts of European Union, although this would arguably under-represent changes at low latitudes, where the majority of biodiversity is found; and, (iv) weight Member States by both land area and species richness, such that changes in countries with high pollinator diversity were up-weighted, and while this would be the most appropriate way to represent biodiversity change across the continent, it has the weakness that it would be harder to communicate than other options.

Eristalis tenax, Maria Luisa Paracchini

6.1.2.9 S-indicators combined with functional trait or phylogenetic information

Combining the state indicators of species richness and occupancy/abundance with morphological and functional traits or phylogenetic information of pollinator species may be helpful for the interpretation of the trends observed (e.g. in terms of linking P-indicators to trends of functional group richness). For example, Powney et al (2019) reported that bee species of agricultural landscapes had increased whereas habitat specialists declined, implying a role for agri-environment schemes in mitigating habitat loss. Functional group richness based on bee traits, which shows correlations to fruit and seed set (Albrecht et al. 2012; Martins et al. 2015) may also be helpful for the development of impact indicators on pollination success (see section 6.1.3 for more details). Functional traits found to be strongly related to pollination function include proboscis morphology (Ibanez 2012), body hairiness (Stavert et al. 2016), and body size (Bartholomée & Lavorel 2019). However, their suitability as indicators may be very limited because the links between these traits and the actual pollination provision may be weak. Body size in pollinators could be a potentially useful trait to consider as it may link the responsiveness to environmental change with ecological functioning at the community (Bartomeus et al. 2018) and population levels (Jauker et al. 2016; Warzecha et al. 2018). Gérard et al. (2019), analysing the shift in size of bumble bee queens, showed that at the community level, species with stable or increasing relative abundance tend to be larger than declining species; though changes in temperature, agricultural intensification and habitat fragmentation were found to be alternative mechanisms that shape body size clines (Gérard et al. 2019).

Pollen-foraging niches is a further trait which could be informative. For instance, for European bumble bees, declining species typically have a narrow dietary niche, using relatively few plant species for collecting pollen, compared to species with more stable populations (Goulson et al. 2005; Kleijn and Raemakers 2008). In case of a loss of plant species, due to environmental change or intensification of agriculture, those species with a narrow foraging niche may be less likely to be able to switch to alternative hosts if their preferred hosts are lost (Wood et al. 2019).

Life history traits such as dispersal ability, trophic level, or sociality may also respond to land-use change. In a community-wide analysis of wild-bee species in fragmented calcareous grasslands, small body size and solitary reproduction were traits that made species particularly vulnerable to habitat loss (Jauker et al. 2013). A refined trait analysis within the bee family Halictidae, however, showed social, as opposed to solitary, wild bee species were more affected by habitat loss. The opposite pattern observed for all wild bees may have been determined by large-sized social bumble bee species with high mobility and large foraging distances (Jauker et al. 2013). This comparison shows the potential risk of concealed trait interference when analysing community-wide patterns of life history traits (Jauker et al. 2013). As a consequence, ecologically meaningful trait combinations should be defined before linking trends in functional diversity of pollinators to trends of pressure indicators.

Working with functional group richness and life-history traits to construct state and perhaps impact indicators would be a worthwhile longer-term aim for better understanding the possible reasons for trend developments. Nevertheless, the options for working with functional group richness and composition as secondary state indicators may be limited by (i) the taxonomic resolution of the pan trap and transect samples within the EU-PoMS surveillance monitoring, and (ii) by the availability of trait information and databases covering the pollinator species of the EU member states. Indeed, many pollinator taxa trait databases are incomplete for many species-trait combinations and often do not capture geographical and intra-species dependent variation (e.g. size, hairiness, lecty and dispersal).

In addition to indicator measures based on functional diversity of pollinators, development of a phylogenetic diversity indicator could potentially complement the above suggested S-indicators. Species loss due to land-use change is not random across the insect phylogeny, and it may result in greater loss in phylogenetic diversity than the species richness loss alone (Grab et al. 2019). The evolutionary diversity and genetically adaptive potential of wild populations are recognised as important components of conservation efforts (though often neglected, see Laikre et al. 2020), and as such could also be considered for the monitoring.

In a recent study by Grab et al. (2019), pollinator communities were shown to contain more closely related species in highly agricultural landscapes compared with those found in landscapes with less agricultural cover. Furthermore, the phylogenetic distance of bee communities alone was a better predictor of the fruit yield in apple orchards than either diversity, abundance or species richness (Grab et al. 2019). A loss of a phylogenetic clade in a pollinator community may lead to a reduction in the suite of functional traits present when these traits show a phylogenetic signal, and thus functional and phylogenetic diversities of pollinators tend to be interlinked. While this approach shows promise, there are major empirical and technical challenges to be addressed before it could be developed as an indicator for the EU-PoMS.

6.1.3 Options for impact indicators

The I-indicators provide information on the impacts of pollinator change or decline (change of state) on ecosystems and ecosystem services. Loss of pollinators, both managed and unmanaged, have direct consequences on insect-pollinated plants, and indirect consequences for other wildlife in natural and agricultural ecosystems (Kuldna et al. 2009; IPBES 2016). For instance, pollinator declines or changes in pollinator communities result in impacts on crop production, with related economic losses, and these could also affect human nutrition, as insect-pollinated crops provide human dietary variety and nutrients (Eilers et al. 2011). The loss of production could also lead to price rises which affect access to nutrition (Gallai et al. 2009). Moreover, changes in pollination of insect-dependent wild plants, and their reproductive success, are likely to have serious consequences for the wider ecological community (Vanbergen et al. 2014).

Although there are well-documented declines in some wild and managed pollinators in several regions of the world (e.g. Potts et al. 2010; IPBES 2016; Powney et al. 2019), evidence on the impacts of these changes on ecosystems and ecosystem services is still scarce on a wider scale. However, some documented impacts have shown the decline of insect-pollinated wild flowers in the UK (Vanbergen et al. 2014), as well as fruit set and seed number of apples suffering potential pollination deficits (Garratt et al. 2014) or the decline of animal-pollinated crops and resulting micronutrient deficiencies globally (Eilers et al. 2011).

Proposals and explanations for the construction of S-indicators, based on the respective taxonomic resolution available for the pan trap and transect data, have been provided in section 6.1.2. To provide a comprehensive picture of the current state of I-indicators on pollination, two approaches for indirect and direct I-indicators are compared here. The first, an indirect approach of deriving a proxy for pollination services could supply capacity from EU-PoMS data (to provide a relative measure). For a more direct measure of pollination services (e.g. bagging experiments), additional data acquisition through the EU-PoMS would be required, but this approach would provide the EU with a much more robust indicator on impacts.

6.1.3.1 Indirect impact indicators

In order to construct an impact indicator derived from data collected through the current sampling scheme proposed for the EU-PoMS (data on species composition, abundance and/or occupancy), a ‘pollination service supply capacity’ could be used. Pollination service supply capacity refers here to the organisms responsible for the pollination function, i.e. pollinating insects. The presence of pollinators is estimated by measures of abundance and richness of pollinating insects, representing measures of the biodiversity of the providers of the pollination service (Bartholomée & Lavorel 2019). The changes in pollination service supply capacity could inform on threats to crop pollination and ecosystem functioning. This type of indirect indicator could be constructed based on three main types of data:

- *Species richness or species diversity.* Maintaining diverse wild pollinator communities is expected to stabilise and improve the delivery of pollination services (e.g. Winfree & Kremen 2009). Therefore, measures of richness and diversity of pollinating insects are linked to the availability of providers of the pollination service (Bartholomée & Lavorel 2019); and can potentially inform on ecosystem services’ supply capacity. However, the abundance of the most common flower visiting species is often a much stronger predictor of pollination than species richness or diversity (Winfree et al. 2015).

- *Functional diversity.* Pollinator functional diversity could potentially be a more relevant indicator of pollination service supply capacity than species richness or diversity, through assessing the impact of changes of state on pollination services. Several studies have shown that functional diversity can have a positive effect on pollination services and help to buffer these from environmental changes (e.g. Hoehn et al. 2008; Mallinger & Gratton 2015). Pollinator functional group or diversity of bee traits have been observed to correlate with fruit and seed set (Albrecht et al. 2012; Martins et al. 2015). Functional traits found to be strongly related to pollination function are proboscis morphology (Ibanez 2012) and body hairiness (Stavert et al.2016). Stavert et al. (2016) showed that insect hairiness, particularly hairiness on the face and thorax, can be used as a robust proxy of single visit pollen deposition and is strongly linked to pollination; though this is only one of the contributing factors to the overall level of pollination service provision.

- *Abundance of dominant species.* Abundance of the most common flower (crop) visiting species is a strong predictor of pollination (Kleijn et al. 2016), and it could be more meaningful than species or functional diversity. In fact, abundance fluctuations of dominant species were found to drive ecosystem service delivery in several agroecosystems in USA, whereas richness changes were relatively unimportant because they primarily involved rare species that contributed little to pollination function (Winfree et al. 2015). For this indicator, a better knowledge of the major pollinators of crops (dominant as well as minor cops) throughout the EU would be helpful and could be an important part of capacity-building within the Member States.

- It is important to highlight that these three options still represent weak proxies of actual pollination service delivery, and as with state indicators, many of the species traits are not well known. Additionally, it could be potentially problematic to construct the impact indicator based on the same data as the state indicator (species abundance, species richness or functional diversity), as it would co-vary with the state indicator. If this type of indirect indicator is eventually implemented, we recommend that the proposed species level taxonomic resolution of the EU-PoMS would be essential to develop an appropriate indirect impact indicator for pollination services.

6.1.3.2 Direct impact indicators

There are additional ways to estimate pollination service supply capacity, or realised flow of the pollination service (reviewed by Bartholomée & Lavorel 2019), which are considered as more direct and robust indicators of impacts. However, to develop these indicators, the collection of additional data through the EU-PoMS would be necessary. Bartholomée & Lavorel (2019) differentiate between three major variables for pollination services' estimation (in addition to pollinator diversity and abundance), each of which can be associated with alternative indicators: (i) pollen transfer, (ii) pollination success, and (iii) harvest for human consumption. Data on pollinator abundance (indirect measures, see 6.1.2) or visitation rate (pollen transfer, see below) alone does not allow direct assessment of the level of pollinator contributions to yield/quality, or pollination deficits in crops or wild plants of conservation value. For this, more direct measures are required, including pollinator exclusion or supplementary pollination techniques. If a monitoring scheme aims to accurately assess changing levels of pollination service to crops over time or space then it should consider including direct assessments of pollination (Garratt et al. 2019).

- *Pollen transfer.* This measure rests on the pollinator's role in transferring pollen between flowers, and is, for example, estimated with visit frequencies and/or pollen transfer efficiency (i.e. the number of pollen grains left during one single visit). Possible indicators include: visit number/visit rate/visit frequency, pollen transfer efficiency, pollen deposit on stigma per visit, pollen quantity held by one individual, and pollen quantity taken per visit.


Lots of insects, Fionn Moore

- *Pollination success.* Plant reproductive success attributable to the action of pollinating insects (rather than wind pollination, self-pollination or plant resource availability), can be estimated through the number of pollen tubes developing, or through seed or fruit production, at the individual plant scale (e.g. seed or fruit number/weight). Possible indicators include: pollen grain number with developed pollen tube, seed/fruit number (unit), fruit/seed mass (fresh or dry), seed/fruit production (% of flowers becoming fruits, % viable seeds), and number of aborted seeds/fruits. One reliable measure to detect impacts on pollination services would be to use in situ crop plants or to deploy 'sentinel' plants at the sample sites. Replicates of these plants would be subject to one of three experimental treatments: (i) an 'open' treatment with unrestricted visitation by local pollinators; a 'closed' treatment which had a mesh bag placed over the stem or branch excluding all biotic pollination; and a 'supplementary' treatment where excess compatible pollen is transferred to the experimental plant through hand pollination. After treatment the plants are allowed to produce seeds/fruit and at harvest the contribution of pollinators to production (i.e. pollination services) can be calculated as the difference between 'open' and 'closed' treatments; pollination deficits can be calculated as the difference between 'supplementary' and 'open' treatments . While this approach is widely considered the best direct measure of pollination services to crops, it requires substantially more time and expertise than other more indirect approaches, and relies on professional surveyors, as it can be challenging for farmers or citizen scientists to undertake (Garratt et al. 2019).

- *Harvest for human consumption.* A final method is to assess the reproductive success of crops attributable to the action of pollinating insects at the field or farm scale. This definition relates to all crops used as food, fodder, biofuel, etc., and is measured in yield per unit area or describes harvest quality for consumption (e.g. the oil content of sunflower seeds or the sugar content of apples). These indicators could comprise: harvest (production per surface unit), seed/fruit quality (shape, relevant properties in their consumption). However, this method does not differentiate between production linked to pollinators vs. production linked to other inputs (such as nutrients), unless the three experimental treatments described above are also applied to representative crop plants to partition out the different contributions to productivity. Yield is affected by many other factors in addition to pollination success (agronomic and environmental factors, the use of managed pollinators for many crops, etc.), which means it is a fluctuating variable and hence not a reliable measure to represent impacts of pollinator decline on pollination services.

- A summary table containing the main type of impact indicators and approaches described, together with their main respective advantages and disadvantages, is presented below (Table 6.2).

Table 6.2. Main types of pollination impact indicators and approaches.

Construction approach and pollinator indicator	Source pollinator data	Focus of the indicator	Additional methods needed	Advantages	Disadvantages	Quality level
A) Indirect proxy of pollination service supply capacity						
• Species diversity or richness	Abundance, occupancy	Pollination service supply capacity	None	Easy implementation	Relative measure	Low
• Functional diversity	Occupancy, species traits	Pollination service supply capacity	None, but needs high taxonomic resolution	Easy implementation	Relative measure; traits unknown for many species	Medium
• Abundance of dominant species	Abundance	Pollination service supply capacity	None, but needs high taxonomic resolution	Easy implementation	Relative measure	Medium
B) Direct measure of pollination service						
• Pollen transfer (e.g. visitation frequency, pollen deposition on stigma per visit)	Timed counts, pollen quantification	Pollination service supply capacity	Timed counts, pollen quantification surveys	Absolute measure	Additional surveys needed; traits unknown for many species	High
• Pollination success (e.g. fruit set, seed set)	Surveys targeted at quantifying pollination services	Realised flow of the pollination service	Crop or sentinel experimental plant manipulations	Absolute measure	Additional surveys needed	High
• Harvest for human consumption (e.g. harvest, fruit or seed quality)	Surveys targeted at quantifying crop yield and quality	Realised flow of the pollination service	Surveys in different farming systems, data already available from farmers or fruit cooperatives?	Absolute measure	Yield is strongly affected by agronomic and environmental factors other than pollination	Low

6.1.4 Options for pressure indicators

Landscape alteration and land-use changes (including urban, agricultural and forest land cover) can be among some of the most severe pressures on pollinators. Pressures include loss and fragmentation of pollinator habitats, lower connectivity, or the loss of resources (food and nesting sites) for pollinators. Landscape composition and configuration are often quantified as indirect indicators, assessing nesting and feeding resources (see 'Indirect landscape indicators' in Bartholomée & Lavorel 2019). For those indirect landscape indicators, however, it has to be considered that different pollinator groups are influenced by different scales and landscape elements (Bartholomée & Lavorel 2019). Indicators of land-use change could include:

- Landscape fragmentation pressure and trends in Europe (EEA Indicator[3])
- Fragmentation of natural and semi-natural areas (EEA Indicator[4])
- Land take in Europe (EEA Indicator[5])
- Ecosystem coverage (EEA Indicator[6])
- Imperviousness and imperviousness change (i.e. extent, degree, dynamics and spatial pattern of surface sealing; EEA Indicator[7])

In addition to land-use change, the intensity of land use (in agriculture and forestry) generates pressures on pollinators and pollination. Of particular relevance are the use of agrochemicals and the intensity of tillage, grazing or mowing as well as general cropping patterns. The suitability of existing indicators on the use of agrochemicals (i.e. mineral fertilisers and pesticides) is limited because they are based on consumption, meaning they are estimated based on the sales of mineral fertiliser and pesticides in the EU. Currently data are not collected in a geo-referenced survey form, or collected on actual application rates, which prohibits the use of these data for modelling environmental impacts at finer spatial scales. The term 'pesticides' refers to various categories of plant protection products (PPP), covering 'fungicides and bactericides', 'herbicides, haulm destructors and moss killers', 'insecticides and acaricides', 'molluscicides', 'plant growth regulators', and 'other plant protection products'. The way in which those pesticides are used (quantities, time and method of application, type of crop, type of soil, mixtures of products applied etc.) influences their effect on non-target organisms such as pollinators and the environment in general. Unfortunately, apart from the crop type, statistics on these factors and on rates applied on farms are not available. Therefore it is not possible to identify suitable indicators of agrochemical pressures on pollinators within the Member States.

There are however, some potential indicators already available from the European Environment Agency and elsewhere:

- Agriculture: nitrogen balance (EEA Indicator[8])
- EU Agri-environmental indicator: mineral fertiliser consumption[9]
- EU Agri-environmental indicator: cropping patterns[10]
- EU Agri-environmental indicator: consumption of pesticides[11]
- Harmonised risk indicator 1[12]
- Forest: growing stock, increment and fellings (EEA Indicator[13])
- Forest: deadwood (EEA Indicator[14])

3 https://www.eea.europa.eu/data-and-maps/indicators/mobility-and-urbanisation-pressure-on-ecosystems-2/assessment
4 https://www.eea.europa.eu/data-and-maps/indicators/fragmentation-of-natural-and-semi-1/assessment-1
5 https://www.eea.europa.eu/data-and-maps/indicators/land-take-3/assessment
6 https://www.eea.europa.eu/data-and-maps/indicators/ecosystem-coverage-3/assessment
7 https://www.eea.europa.eu/data-and-maps/indicators/imperviousness-change-1/assessment
8 https://www.eea.europa.eu/data-and-maps/indicators/agriculture-nitrogen-balance-1/assessment
9 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption
10 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_cropping_patterns
11 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides
12 https://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/harmonised-risk-indicators_en
13 https://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings-3/assessment
14 https://www.eea.europa.eu/data-and-maps/indicators/forest-deadwood-1/assessment-1

Eurostat publish data on the total sales, and therefore use, of PPPs (including both chemical and non-chemical PPPs) each year. However, this data provides a crude measure of the risks linked to PPPs, as in some cases relatively more hazardous PPPs are used at very low quantities per hectare (which helps to reduce the total quantity sold/used), while relatively less hazardous substances are used at much higher quantities per hectare (thereby contributing to an increase in the total quantity sold/used). Consequently, total sales, and therefore use, of PPPs is not a good measure of the risk linked to PPPs, including the risks to pollinators. Nevertheless, in a general sense, it is expected that a lower use of PPPs would help to lower the pressure on pollinators. The harmonised risk indicator 1, established by the Commission under Directive 2009/128/EC, estimates the trend in the risks associated with the PPPs placed on the market (sold), and therefore used. It is determined by multiplying the quantities of PPPs sold in different categories in each Member State, by a weighting to reflect the intrinsic hazardous properties of the active substances in these PPPs. The indicator decreases if fewer PPPs are sold/used and/or low-risk PPPs make up a higher proportion of sales/use. Therefore, it encourages both a reduction in overall sales/use of PPPs, and a shift towards low-risk PPPs, and away from the most hazardous PPPs.

In addition to the EU and EEA indicators, national projects and initiatives are collating baseline information on land-use intensity, such as the intensity of plant protection in agriculture, forest and urban areas, and could be harnessed for P-indicator reporting (e.g. PROTECTS project[15]). Suggestions for ways to assess pollination potential of agricultural landscapes, based on transect vegetation surveys in EU member states, are made by the EMBAL project[16].

The impact of invasive alien species on pollinators and pollination strongly depends on the identity of the invasive species and the ecological and evolutionary context (IPBES 2016). The invasive alien species can comprise alien plants, alien pollinators, alien predators, alien herbivores and alien plant or insect pathogens (pests and diseases). A full record at the member state level may be difficult to acquire, although an EU-level indicator is available:

- Invasive alien species in Europe (EEA Indicator[17])

In addition, some data are available on invasions by plants, pathogens or insects affecting pollinators tracked within respective Member States[18]. For making concrete use of such lists of invasive alien species, their respective relevance for pollinators and pollination would have to be further investigated and identified. The European Alien Species Information Network - EASIN[19] may be a platform for such action, perhaps with the use of citizen-science approaches.

A change in climatic conditions can have direct physiological impacts on pollinators and pollination, and indirect impacts through changes in seasonal activity of species, disrupted life cycles and geographical or phenological mismatches of pollinators from their food plants. An increase in frequency of extreme temperatures may also affect pollinators such as bumble bees (Soroye et al. 2020). Relevant pressure indicators could therefore include changes in climatic and weather conditions, as well as changes in air pollution and the phenology of plants and cropping systems:

- Forest composition and distribution (EEA Indicator[20])
- Agrophenology (EEA Indicator[21])
- Phenology of plant and animal species (EEA Indicator[22])
- Mean precipitation (EEA Indicator[23])
- Heavy precipitation in Europe (EEA Indicator[24])
- Forest fires (EEA Indicator[25])

15 For example: PROTECTS project https://protects.ucd.ie/
16 http://ec.europa.eu/environment/nature/knowledge/pdf/embal_report.pdf; http://ec.europa.eu/environment/nature/knowledge/pdf/embal_survey_manual.pdf
17 https://www.eea.europa.eu/data-and-maps/indicators/invasive-alien-species-in-europe/invasive-alien-species-in-europe
18 For example: National Biodiversity Data Centre http://www.biodiversityireland.ie/projects/invasive-species/
19 https://easin.jrc.ec.europa.eu/easin
20 https://www.eea.europa.eu/data-and-maps/indicators/forest-growth-2/assessment
21 https://www.eea.europa.eu/data-and-maps/indicators/timing-of-the-cycle-of-2/assessment
22 https://www.eea.europa.eu/data-and-maps/indicators/plant-phenology-2/assessment
23 https://www.eea.europa.eu/data-and-maps/indicators/european-precipitation-2/assessment
24 https://www.eea.europa.eu/data-and-maps/indicators/precipitation-extremes-in-europe-3/assessment-1
25 https://www.eea.europa.eu/data-and-maps/indicators/forest-fire-danger-3/assessment

- Air pollution due to ozone: health impacts and effects of climate change (EEA Indicator[26])

Monitoring of honey bee health and occurrence of pathogens and parasites exists within some Member States (e.g. DeBiMo - Deutsches BienenMonitoring[27]), but to our knowledge there is no monitoring of pathogens and parasites of wild bees or other pollinators. To date there has been no study of wild bee parasites that has generated consistent data across wide geographic regions of Europe, and for viruses of bees there has only been a one-off survey within the Super-B project[28].

Some declines of pollinators and pollination are probably exacerbated by both the individual and combined effects of multiple pressures (IPBES 2016), and therefore the interrelationships between the pressure indicators will be important to recognise and assess. The greater the spatial and temporal resolution of the data behind P-indicators, the better they could be used for interpreting trends in pollinators and pollination. Access to available data such as land-use information from the Integrated Administration and Control System (IACS)[29] that has been set up by all Member States to manage the implementation of the Common Agricultural Policy[30], and its Land Parcel Identification System (LPIS)[31] is vital for the success of any kind of biodiversity monitoring.

In the EU Member States, mitigating actions on environmentally adverse effects of land use change, land use intensity and climate change are widely implemented. Some of these actions may have direct or indirect positive effects on pollinators and pollination, and therefore can also contribute to the list of P-indicators:

- Nationally designated protected areas (EEA Indicator[32])
- Sites designated under the EU Habitats and Birds Directives (EEA Indicator[33])
- Habitats of European interest (EEA Indicator[34])
- Agriculture: area under management practices potentially supporting biodiversity (EEA Indicator[35])
- Area under organic farming (EEA Indicator[36]) and Organic farming statistics[37]

Historically, some mitigating actions did not result in halting or reversing the negative trends of some biodiversity indicators, such as farmland birds. Their usefulness as mitigation indicators for pollinators therefore strongly depends on their quantitative and qualitative developments in the future. For instance, while organic farming can often be beneficial to pollinators, the need for increasing the yield from organic farming can decrease the benefits organic farming practices accrue for some biodiversity (Gabriel et al. 2013).

6.1.5 Options for response indicators

Response indicators can provide useful information about existing actions, and also increase awareness about the problem of pollinator and pollination decline in Member States and across the EU. The assessment of the P-, S-, and I-indicators from the Member States and Europe could potentially show whether there is a positive relationship between the R-indicators and the direction of the trends shown by the P-, S- and I-indicators. If positive trends of R-indicators do not translate into positive trends of pollinators and pollination in the long term, or if they are disconnected (i.e. do not co-vary), then this may be evidence that the response by policy and/or society is for some reasons not resulting in the changes necessary for improving the protection of pollinators. Such information can then be used to inform on what policy amendments are required. However, an observed disconnection may also be due to constraints of the monitoring scheme, such as high variability in pollinators between years, lag effects of interventions, and generally high noise when trying to assess effectiveness of interventions which have not been implemented in a design to facilitate testing their impact (see section 6.2). Ideally, the inferences drawn from the P-, S-, and I-indi-

26 https://www.eea.europa.eu/data-and-maps/indicators/air-pollution-by-ozone-2/assessment
27 https://bienenmonitoring.uni-hohenheim.de/
28 http://superb-project.eu/
29 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/controls-and-transparency/managing-payments_en
30 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/cap-glance_en
31 https://op.europa.eu/en/publication-detail/-/publication/11049e0e-9a82-11e6-9bca-01aa75ed71a1
32 https://www.eea.europa.eu/data-and-maps/indicators/nationally-designated-protected-areas-10/assessment
33 https://www.eea.europa.eu/data-and-maps/indicators/sites-designated-under-the-eu-2/assessment
34 https://www.eea.europa.eu/data-and-maps/indicators/habitats-of-european-interest-1/assessment
35 https://www.eea.europa.eu/data-and-maps/indicators/agriculture-area-under-management-practices/agriculture-area-under-management-practices-2
36 https://www.eea.europa.eu/data-and-maps/indicators/area-under-organic-farming-1/area-under-organic-farming-assessment-1
37 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Organic_farming_statistics

Episyrphus balteatus, Tamara Tot

cators could be used to trigger research into the exact amendments required to attain a better connection between the response action and the delivery of pollinator habitats and other resources. Some examples of relevant capacity building R-indicators are presented in sections 7.1 and 7.2, in particular related to awareness within the Member States, such as the state of taxonomic knowledge[38] and expertise, the existence of species inventories (e.g. checklists) and Red Lists[39]. The existence of concrete actions and incentives within Member States could be indicated by reporting about the status of, amongst other aspects:

- A National pollinator/pollination strategy[40]
- Incentives for the support/conservation of pollinators (in urban, agricultural, and forested)areas
- Actions, regulations or incentives to reduce perverse incentives counteracting pollinator strategies
- Pollinator monitoring programmes.

6.1.6 Integrated monitoring using combinations of indicators

Volunteers and citizen science monitoring are an important integral element of future monitoring, both for surveillance and question-driven monitoring; section 7.3.1.2 provides a detailed discussion on how to strengthen and support volunteer recorders for the EU-PoMS. To promote and support citizen science is already an important aspect of the EU Pollinators Initiative, and the Commission is currently producing guidelines and an inventory[41]. An integration of monitoring activities and indicators across people, stakeholders and data types is expected to bring substantial benefits for robust analyses to address a wide range of questions on the patterns and causes of large-scale biodiversity change (Henry et al. 2008; Honrado et al. 2016; IPBES 2019).

38 For example: Atlas of the wild bees of Brussels (https://www.wildbnb.brussels); Irish national databases on bees and syrphids (https://pollinators.ie/record-pollinators/bees/national-database/; https://pollinators.ie/record-pollinators/hoverflies/national-database/)

39 For example: Irish bee Red Lists https://www.npws.ie/sites/default/files/publications/pdf/Fitzpatrick_et_al_2006_Bee_Red_List.pdf

40 For a first overview see: https://ec.europa.eu/environment/nature/conservation/species/pollinators/documents/ieep_2017_pollinator_initiatives_in_eu_member_states.pdf

41 https://data.jrc.ec.europa.eu/dataset/jrc-citsci-10004

However, such an integrated approach of monitoring and indicators faces several challenges (inter alia technical, social, data sharing, statistical) which still need to be overcome but are in progress.

An example of citizen science monitoring of pressure and mitigating actions is the INSIGNIA project[42] which is developing protocols for a citizen science monitoring programme using beekeepers to collect pollen samples from honey bee colonies for analysis of pesticide residues and botanical origin and an online mapping system for tracking of new pollinator-friendly habitats being created by community groups, businesses, councils, schools, and individuals in Ireland.[43] A further example is the Honey Monitoring Scheme in the UK, measuring plant composition, pesticide residues and diseases from honey collected by beekeepers from their hives.[44]

6.2 Common Agriculture Policy (CAP) pollinator indicators

6.2.1 Policy context for a pollinator indicator

The European Commission (EC) is working on a new Performance Monitoring and Evaluation Framework (PMEF)[45] designed to meet the unified performance framework of the CAP. Novel aspects in comparison to the previous CAP are that objectives of the CAP[46], broad types of interventions and basic requirements will be set by the EU whereas CAP interventions will be set by the Member States, tailored to their specific needs. Thus, Member States will have more flexibility and responsibility in order to define their needs according to the local conditions to shift from a one-size-fits approach towards more tailored interventions. To address the key environmental objectives of the CAP, each Member State will draw up a 'CAP strategic plan' for which it will analyse the situation on its territory based on a SWOT-analysis, as well as its related needs (DG Agriculture and Rural Development, 2019). In respect of these objectives, quantified targets against the objectives will be set by the Member State and 'interventions' (types of action) for achieving them will be designed. This overall approach will apply to both 'pillars' of the CAP together. Such a Member State-specific, needs-based approach creates greater ownership by Member States on how they integrate and implement the Green Architecture elements[47], allowing regional tailoring to local farming systems and conditions. The impact of the CAP on future land use and land management in agricultural landscapes will most likely be strongly Member State-specific. It is to be expected that the fostering and mitigating impacts of CAP measures on farmland biodiversity, including pollinators, will differ between Member States. This has implications on the choice of biodiversity monitoring and CAP evaluation schemes and selection of indicators suitable for evaluating the impact of CAP interventions.

The European Commission proposes to include a pollinator performance indicator within the post-2020 CAP monitoring framework, highlighting its commitment to conserve pollinators. Cole et al. (2020) recommend an effective monitoring framework alongside appropriate target-orientated indicators (e.g. a specific pollinator indicator in addition to other indicators of ecosystem health, such as the EU Butterfly Grassland Indicator[48]). To safeguard pollinators in agroecosystems, the post-2020 CAP interventions would have to be designed to ensure that pollinators have access to all necessary resources in sufficient quantities. For this the CAP needs progress to explore options that improve habitat quantity, habitat quality, connectivity and complementarity for pollinators (Cole et al. 2020). Robust monitoring and hence sufficient data on the level of resources currently present in a landscape is largely lacking. The current CAP proposal includes a specific result indicator on landscape features (R.29 Preserving landscape features: Share of agriculture land under commitments for managing landscape features, including hedgerows) and an impact indicator (I.20 Enhanced provision of ecosystem services: share of UAA covered with landscape features). These two landscapes indicators are under development.

The next section presents a roadmap and decision tree for the construction of a pollinator performance indicator in the framework of CAP impact evaluation. Options for monitoring schemes and adapted indicators are presented.

6.2.2 A roadmap for the construction of a CAP pollinator impact indicator

Monitoring and indicators should provide a sound analytical basis for future policy design by providing an understanding about the effectiveness of measures and interventions and the achievement of the objectives set, thus supporting policy developments (EC 2015). Evaluation of the CAP goes even deeper than the monitoring, as it involves a judgement of interventions according to the results, impacts and needs they aim to achieve (EC 2015). Evaluation as a systematic tool should provide

42 https://www.insignia-bee.eu/
43 https://pollinators.ie/record-your-actions/
44 https://honey-monitoring.ac.uk/
45 https://enrd.ec.europa.eu/evaluation/common-monitoring-and-evaluation-framework-cmef-common-monitoring-and-evaluation-system-cmes_en
46 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en#objectives
47 https://www.europarl.europa.eu/cmsdata/159941/New%20green%20architecture%20-%2024.01.2019%20-%20Presentation%20Commissioner%20Hogan.pdf
48 https://www.eea.europa.eu/data-and-maps/figures/european-grassland-butterfly-indicator

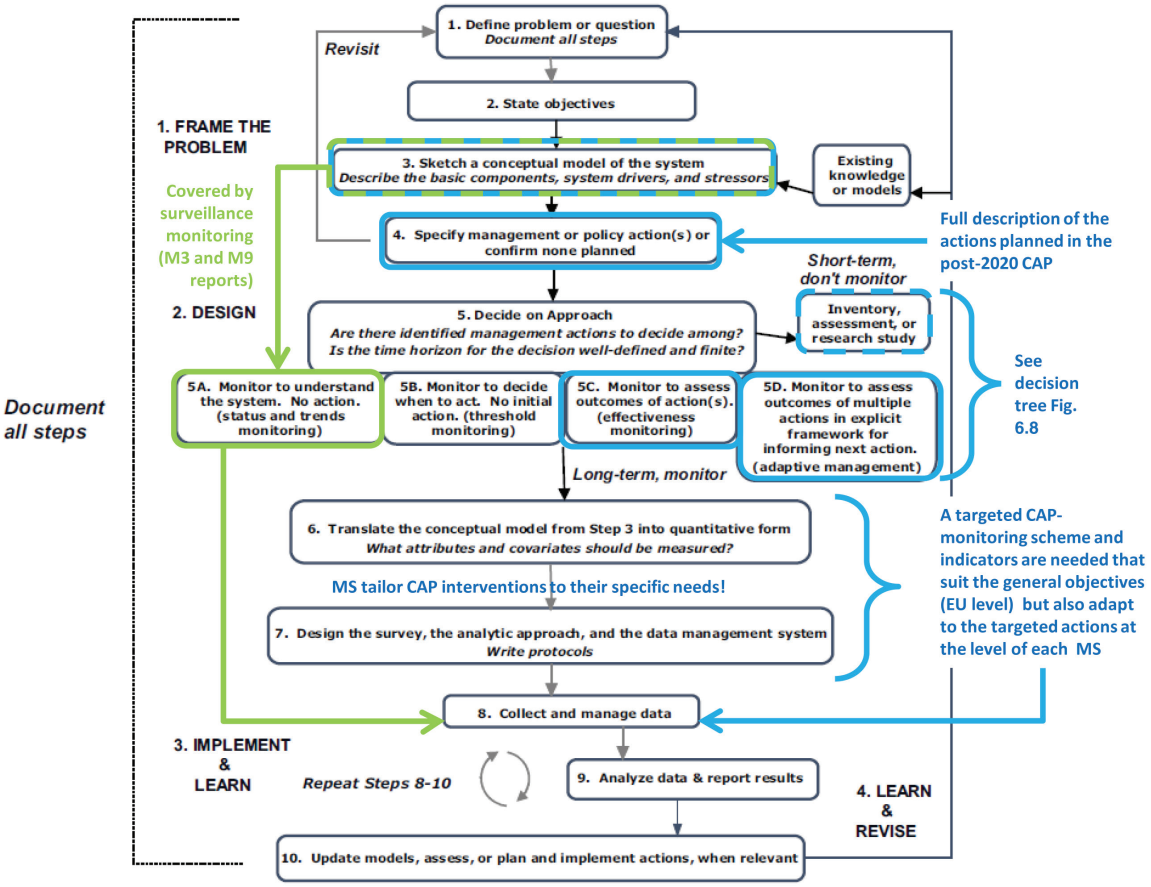
Eristalis tenax, Adara Pardo

evidence for decisionmaking to improve effectiveness, usefulness and efficiency of measures and interventions. Fulfilling such an ambitious demand will not be possible with a one-size-fits-all approach relying on a small set of indicators, but will require the monitoring of a range of quantities in order to measure trends or provide ad hoc environmental insights (Nichols and Williams 2006). Here we present the key decisions which have to be made for designing a conceptual framework to capture the interplay of monitoring and evaluation schemes, and related sets of indicators to achieve those demands for a CAP impact indicator for pollinators and for pollination.

The CAP impact indicator for pollinators and pollination should be designed to provide an evaluation of how measures and incentives implemented in the CAP at the Member State and sub-national scale affect the level of resources for pollinators in the agricultural landscape (P-indicators; see section 6.1.4). Furthermore, S- and I-indicators of pollinators and pollination should show CAP-related changes in trends that can ideally be interpreted separately from the overall trend of S- and I-indicators reported from the general surveillance monitoring (sections 6.1.2 and 6.1.3). Hence, in contrast to the general surveillance monitoring (sections 5.2 and 6.1), the CAP evaluation needs to be designed to answer concrete questions but covering different spatial and temporal levels. Due to the sub-national targeting of measures and interventions by Member State, it would be necessary to evaluate both the short- and long-term efficacy of CAP measures first at the sub-national scale. The evaluations then would be up-scaled to the Member State level and, from there, compiled for the EU level.

For the Member State specifically tailored, needs-based CAP measures, concrete hypotheses need to be developed on how those measures may effectively mitigate the negative impacts of agriculture on pollinators and pollination (i.e. a "representation of how key components and ecological processes of a target ecosystem or population interact and/or influence one another" Lindenmayer & Likens 2010). Targeted (or question-based) monitoring can then be designed to be optimal to test a priori hypotheses. The first step in building the hypotheses and formulating appropriate questions that can be evaluated is not a trivial task. The Delphi-study by Cole et al. (2020) has provided an example of how this may be achieved. The study has evaluated the effectiveness of CAP measures *ex post*. For the post-2020 CAP, such a Delphi-study would have to be conducted ex ante to provide an evaluation of the potential effects of the novel CAP measures and hence the basis for the development of the Member State specific evaluation schemes. Building on the concepts of Reynolds et al. (2016) for designing and implementing a biological monitoring programme, we have developed a roadmap for the construction of a CAP pollinator indicator (Figure 6.7). Following this roadmap for an EU Pollinator Monitoring Scheme, steps 1 to 3 have been covered and described in the descriptions of the general surveillance monitoring (sections 5.2 and 6.1). Of particular relevance for the development of the CAP pollinator monitoring is step 4 (Figure 6.7). Here is a full description of the Member State strategic plan and the resulting measures and interventions required. Based on this, questions can be formulated which will help, along a decision tree (Figure 6.8; adapted from Reynolds et al. (2016)), deciding which type of monitoring/evaluation will be required. The road map (Figure 6.7) shows the distinction between the surveillance monitoring (green path) and the targeted, question-driven CAP monitoring (blue path). Both pathways will, however, still interact, either in the process of data collection, management and interpretation (step 8, Figure 6.7) or even by providing complementary monitoring sites (option 2 of CAP monitoring in Figure 6.9).

Figure 6.7. Roadmap for the development of the CAP indicator, based on Reynolds et al. (2016). The pathway in green resembles the general surveillance monitoring of the EU Pollinator Monitoring Scheme (section 6.1), the blue pathway the CAP impact indicator monitoring. MS: member state, EU: European Union, CAP: Common Agricultural Policy.



Step 5 shows which decisions need to be made for the type of monitoring needed. The CAP pollinator indicator especially requires effectiveness monitoring (5C) which in its most basic form involves documenting system response and noting the degree to which the desired outcome was attained (Reynolds et al. 2016). If knowledge about the effectiveness of a certain measure needs to be achieved quicker, for example because the measure should be regionally adapted or 'fine-tuned', no long-term monitoring may be required but the question may be answered by a review of the existing data and literature (meta-analysis) or, if no prior knowledge is available, by a focused study (Figure 6.8). Many aspects of the CAP involve adaptive management, i.e. a formal framework for iterative decision making in the face of large uncertainty regarding how a system will respond to a set of potential actions (Reynolds et al. 2016). Adaptive monitoring (5D) can help both to reduce uncertainty in system state and to reduce uncertainty in expected responses to management actions. A detailed description of the different types of monitoring and what they encompass is provided in Reynolds et al. (2016).

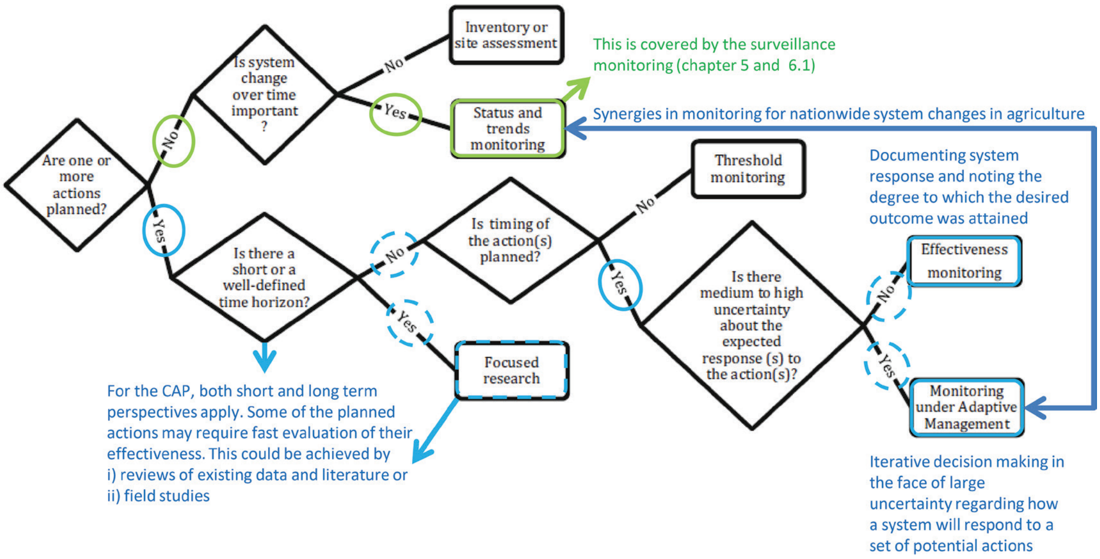
6.2.3 Options for a CAP pollinator impact indicator monitoring

The CAP impact indicator[49] for pollinators and pollination should provide an evaluation of measures and incentives implemented in the CAP. Such an evaluation is different from the general surveillance monitoring (section 5.2) as it has to be designed to answer a concrete question: do the CAP measures[50] effectively mitigate the negative impacts of agriculture on pollinators and

49 CAP impact indicators are measuring the impact of policy interventions for the longer term and when there are effects beyond the immediate period (of which some are also included in the context indicator set). This may not be confused with the I-Indicators of the DPSIR framework.

50 'CAP measures' here and in the following should be understood as all CAP-related measures, payments and interventions within the respective Member States.

Figure 6.8. Decision tree for monitoring of the CAP pollinator impact indicator, based on Reynolds et al. (2016).



pollination and maintain or encourage positive farming practices for pollinators (e.g. maintenance of semi-natural habitats). The P-indicators therefore have to be tightly connected to the desired mitigation of pressures on pollinators. If the adoption of CAP measures by farmers results in a more or less even distribution of those measures across agricultural landscapes, it may well be possible to select all the study sites for CAP monitoring from the EU-PoMS surveillance monitoring site network which is dominated by agricultural land cover for evaluating those measures (albeit a proper control including agricultural landscapes without measures would then be missing[51]). In the Swiss farmland biodiversity monitoring programme ALL-EMA[52] for example, the extent to which the diversity and quality of species and habitats are capable of being preserved or increased by specific Biodiversity Protection Areas (BPAs) is evaluated (Riedel et al. 2018). The low extent of BPA types in the utilised agricultural area of the basic programme sample sites results in random and hence inadequate representation of these target categories (Riedel et al. 2018). For this reason, the basic programme needs adjustment such as extra sampling and prioritised selection of less-common BPA types. Still, in Switzerland BPAs have such a high presence in farmland areas that they can be depicted by the sampling squares. If, however, only around 5% of the utilised agricultural area of EU member states would show a change in land use due to adoption of CAP measures, the chance of depicting those measures in all their variation within the number of sampling sites suggested for the respective Member States (section 5.2.1) is quite low. Therefore, the monitoring of S- and I-indicators has to be conducted in those regions that are responding by adopting certain CAP measures. Thus, the evaluation of the measures may require additional sampling sites (besides the EU-PoMS surveillance monitoring sites) to cover the variety and variability of the respective CAP measures. The S- and I-indicators can basically be the same as the ones developed for the EU-PoMS (sections 6.1.2 and 6.1.3) but the selection of sampling sites has to be informed by the spatially-explicit analysis of the adoption and location of CAP measures within the Member States (Figure 6.9). For such an analysis IACS and LPIS data are urgently required. However, there are several challenges associated with the analysis of the spatial pattern of CAP measures and the intended evaluation of their impact, including: (i) the time lag between the adoption of the measures and the availability of this information for analyses via IACS data[53], and (ii) the lag period for a measure to have impact on the pollinators. Even if IACS data were accessible for research and monitoring, which is currently not the case in many EU countries, the time gap could be at least one year and even longer when adding the time necessary for the spatial analyses and the formulation of questions and hypotheses on the potential impacts on pollinators. So the pollinator sampling would have to start much later than the actual implementation of the measure, impeding a real time evaluation of the measures. Therefore, depending on the concrete arrangement of the CAP and amendments in the availability of IACS data, the feasibility of building such a conceptual model for the CAP impact indicator has to be addressed.

Options for designing a CAP pollinator impact indicator monitoring are sketched in Figure 6.9, for 1) Farm network and 2) CAP sites. In the pre-CAP implementation phase, EU and the Member States interact on the development of the CAP strategic plan. The Member States would conduct SWOT analyses to define their needs and targets for the development of the Member States

51 In countries such as Finland, in which practically all farmland area is CAP-supported, it would not be possible to measure a CAP impact indicator meaningfully because of the almost complete lack of non-CAP-supported areas with which to compare. Nevertheless, here a design for analysing the response of pollinators along a gradient of density of specific CAP measures per unit area may be possible instead.

52 https://www.agroscope.admin.ch/agroscope/en/home/topics/environment-resources/monitoring-analytics/all-ema.html

53 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/financing-cap/controls-and-transparency/managing-payments_en

Eristalis tenax, Tamara Tot

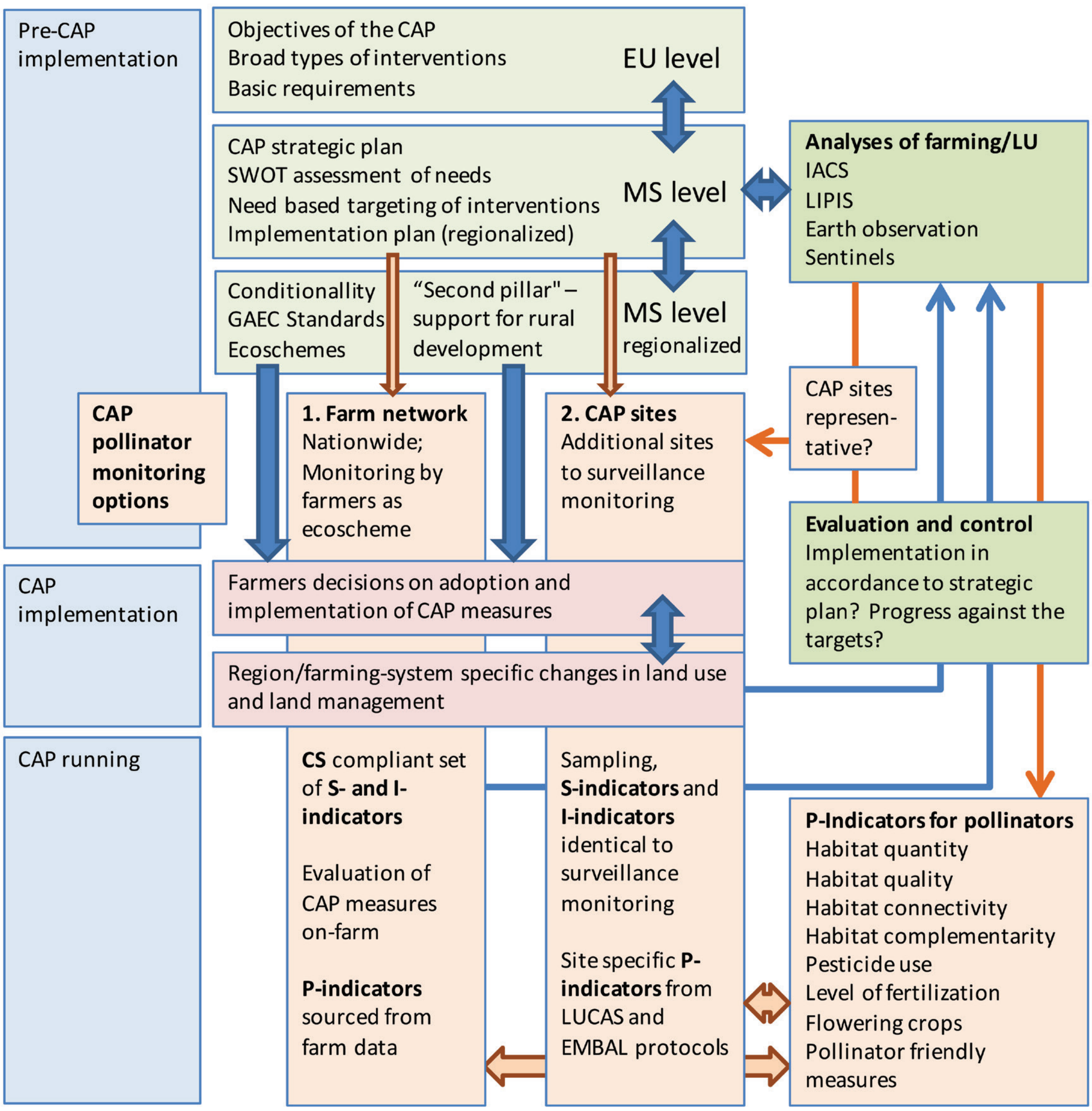
-specific measures and interventions. For this, farming systems and land use in the Member States would be analysed, most likely using information from earth observation (EO) programmes (Copernicus Sentinel[54]) as well as from the IACS data. The same data sources and instruments will be used after the CAP implementation for the evaluation of how far strategic plans have been met (Figure 6.9). This feedback and evaluation mechanism is also helpful for the design of the CAP pollinator monitoring of option 'CAP sites' (Figure 6.9). A regionalised implementation plan of measures and interventions at the level of Member State could be used in the pre-CAP implementation phase to assess whether, and to what degree, the monitoring sites of the surveillance monitoring (section 5.2.1) cover the regions within a Member State in which targeted measures are planned to be established. For those regions where no such monitoring sites exist, additional sites could be established in the Member State so that a representative number of sites for the evaluation of the CAP are achieved ("CAP sites" option in Figure 6.9). For this, a Member State specific power analysis may be required to assess how many additional sites would be needed to complement the sites for surveillance monitoring. A control, with and without CAP measures will not be available because over 90 % of the utilised agricultural area is under CAP, but the sites could resemble different types and different levels of CAP implementations, making comparisons and evaluations of impacts possible. The S- and I-indicators presented in sections 6.1.2 and 6.1.3 would be applicable for this monitoring. The P-indicators (Figure 6.9) could be derived from the CAP implementation evaluation (IACS and EO based), nationwide and for the respective monitoring sites. This approach depends upon a close match between the strategic plan with its regionalised targets and the adoption of the measures by the farmers. If the farmers respond in their land-use and land-management decisions in a way that the spatial pattern of CAP implementation matches the forecast laid down in the strategic plan, the site selection would be appropriate for the CAP evaluation. If, however, the evaluation of the implementation of the CAP (via IACS and EO) shows a mismatch to the strategic plan, a reassessment of the monitoring sites' locations would have to be conducted, delaying the start of the monitoring actions. Option 1 'Farm network' (Figure 6.7) would, by contrast, be relatively independent of the realised pattern of CAP implementation in the Member State, if a large enough network of farms covering a representative share of the utilised agricultural area of a Member State would be achieved. Option 1 involves the farmers as active partners in the monitoring actions. An incentive for contributing to the action could be recognition of the monitoring as part of the Ecoscheme[55] obligations. This is a scenario in which farmers themselves monitor pollinators and pollination on their farms, acting as citizen scientists, and evaluate the measures they have implemented on their farmland. In order to

54 https://open.esa.int/copernicus-sentinel-satellite-data/
55 https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/future-cap_en

facilitate this, different indicators from the ones recommended for the general surveillance monitoring would be needed. The indicators and the mode of observation would have to be more strongly informed by citizen science approaches to monitoring. One possibility would be to survey flower visitation (section 5.4.2) as used in the UK Pollinator Monitoring Scheme (section 1.2.3). Alternatively, the farmers could use pan traps to collect pollinator samples following a simplified protocol (adapted from section 5.4.2). This procedure could be directly comparable to a part of the pan trap sampling (e.g. 1–2 sets of three pan traps 1–2 times during the best pollinator season) included in the general surveillance monitoring (i.e. random areas within farmland). This approach would also necessitate sending the pan trap catches to an expert for identification. Using pan traps for an effective CAP impact monitoring would give the opportunity to combine the data from the CAP monitoring with the pan trap data from the surveillance monitoring (e.g. Bowler et al. 2019 or Isaac et al. 2020). Pollinator trends may then be compared more closely between these two categories of comparable pan trap samples. An advantage with the pan traps would also be that the same S indicators (type 1a and b) could be used in both the CAP and the general pollinator indicator. For such a citizen science approach, however, a non-lethal way of data sampling may be preferential.

The advantage of option 1 over option 2 would be a timely (starting with the implementation of the measures) and (if successful) nationwide coverage of the evaluation. A potential disadvantage is the expectedly lower quality of the monitoring data in terms of taxonomic resolution and a lower complementarity with the data from the surveillance monitoring.

Figure 6.9. Workflow and options for the CAP pollinator monitoring. P-Indicators for pollinators may include CAP context/impact indicators. MS: Member State.



References

Albrecht M, Schmid B, Hautier Y & Müller CB (2012) Diverse pollinator communities enhance plant reproductive success. Proceedings of the Royal Society B: Biological Sciences 279, 4845-4852.

Bartholomée O, Lavorel S (2019) Disentangling the diversity of definitions for the pollination ecosystem service and associated estimation methods. Ecological Indicators 107, 105576.

Bartomeus I, Cariveau DP, Harrison T & Winfree R (2018) On the inconsistency of pollinator species traits for predicting either response to land-use change or functional contribution. Oikos 127, 306–315.

Bowler DE, Nilsen EB, Bischof R, O'Hara RB, Yu TT, Oo T, … Linnell JDC (2019) Integrating data from different survey types for population monitoring of an endangered species: the case of the Eld's deer. Scientific Reports. doi:10.1038/s41598-019-44075-9

Cole LJ, Kleijn D, Dicks LV, Stout JC, Potts SG, Albrecht M, Balzan MV, … and Scheper J (2020) A critical analysis of the potential for EU Common Agricultural Policy measures to support wild pollinators on farmland. Journal of Applied Ecology 57: 681– 694

Dambly L, O'Hara B, & Golding N (2019) oharar/IM_warbler: Integrated analysis of black-throated blue warbler data from PA, USA. doi:10.5281/ZENODO.3363936 (August 8)

DG Agriculture and Rural Development (2019) THE POST-2020 COMMON AGRICULTURAL POLICY: ENVIRONMENTAL BENEFITS AND SIMPLIFICATION. European Union, 2019; https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-post-2020-environ-benefits-simplification_en.pdf

Díaz S, Demissew S, Carabias J, Joly C, Lonsdale M, & Zlatanova D (2015) The IPBES Conceptual Framework – connecting nature and people. Current Opinion in Environmental Sustainability 14, 1–16.

EEA (1999) Environmental indicators: Typology and overview. Technical report No 25/1999, 19 pp.

Eilers EJ, Kremen C, Greenleaf S, Garber AK & Klein A-M (2011) Contribution of pollinator- mediated crops to nutrients in the human food supply. PLoS One 6(6): e21363.

European Commission (2015) The Monitoring and Evaluation Framework for the Common Agricultural Policy 2014–2020. European Union, 2015, 28 pp.

Gabriel D, Sait SM, Kunin WE, & Benton TG (2013) Food production vs. biodiversity: comparing organic and conventional agriculture. Journal of Applied Ecology 50, 355–364.

Gabrielsen P, Bosch P (2003) Internal Working Paper Environmental Indicators: Typology and Use in Reporting. European Environment Agency, Copenhagen. 20 pp.

Gallai N, Salles J-M, Settele J, Vaissière BE (2009) Economic valuation of the vulnerability of world agriculture confronted with pollinator decline. Ecological Economics 68, 810–821.

Garratt MPD, Truslove CL, Coston DJ, Eva RL, Mos ED, Dodson C, Jenne N, Biesmeijer JC and Potts SG (2014) Pollination deficits in UK apple orchards. Journal of Pollination Ecology 12, 9–14.

Garratt MPD, Potts SG, Banks G, Hawes C, Breeze TD, O'Connor RS & Carvell C (2019) Capacity and willingness of farmers and citizen scientists to monitor crop pollinators and pollination services. Global Ecology and Conservation, 20, e00781.

Gérard M, Martinet B, Maebe K, Marshall L, Smagghe G, Vereecken NJ, Vray S, Rasmont p & Michez D (2019) Shift in size of bumblebee queens over the last century. Global Change Biology 00: 1– 11. https://doi.org/10.1111/gcb.14890

Goulson D, Hanley ME, Darvill B, Ellis JS & Knight ME (2005) Causes of rarity in bumblebees. Biological Conservation 122, 1–8.

Grab H, Branstetter MG, Amon N, Urban-Mead KR, Park MG, Gibbs J, Blitzer EJ, Poveda K, Loeb G & Danforth BN (2019) Agriculturally dominated landscapes reduce bee phylogenetic diversity and pollination services. Science 363, 282–284.

Gregory RD, Van Strien A, Vorisek P, Gmelig Meyling AW, Noble DG, Foppen RP & Gibbons DW (2005) Developing indicators for European birds. Philosophical Transactions of the Royal Society B: Biological Sciences 360, 269–288.

Henry PY, Lengyel S, Nowicki P, Julliard R, Clobert J, Čelik T, ... & Henle K (2008) Integrating ongoing biodiversity monitoring: potential benefits and methods. Biodiversity and Conservation 17, 3357–3382.

Hilborn R (1987) Living with Uncertainty in Resource Management. North American Journal of Fisheries Management 7, 1–5.

Hoehn P, Tscharntke T, Tylianakis JM & Steffan-Dewenter I (2008) Functional group diversity of bee pollinators increases crop yield. Proceedings of the Royal Society B: Biological Sciences 275, 2283–2291.

Honrado JP, Pereira HM & Guisan A (2016) Fostering integration between biodiversity monitoring and modelling. Journal of Applied Ecology 53, 1299–1304.

Ibanez S (2012) Optimizing size thresholds in a plant-pollinator interaction web: towards a mechanistic understanding of ecological networks. Oecologia 170, 233–242.

IPBES (2016) The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production. S.G. Potts, V. L. Imperatriz-Fonseca, and H. T. Ngo (eds). Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, Bonn, Germany. 552 pp.

IPBES (2019) Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. E. S. Brondizio, J. Settele, S. Díaz, and H. T. Ngo (editors). IPBES Secretariat, Bonn, Germany https://www.ipbes.net/news/ipbes-global-assessment-summary-policymakers-pdf

Isaac NJB, Jarzyna MA, Keil P, Dambly LI, Boersch-Supan PH, Browning E, ... & O'Hara RB (2020) Data Integration for Large-Scale Models of Species Distributions. Trends in Ecology & Evolution, 35, 56-67. doi:10.1016/J.TREE.2019.08.006

Jauker B, Krauss J, Jauker F & Steffan-Dewenter I (2013) Linking life history traits to pollinator loss in fragmented calcareous grasslands. Landscape Ecology 28, 107–120.)

Jauker F, Speckmann M & Wolters V (2016) Intra-specific body size determines pollination effectiveness. Basic and Applied Ecology 17, 714–719.

Jetz W, McGeoch MA, Guralnick R, Ferrier S, Beck J, Costello MJ, ... & Turak E (2019) Essential biodiversity variables for mapping and monitoring species populations. Nature Ecology and Evolution. doi:10.1038/s41559-019-0826-1

Kissling WD, Ahumada JA, Bowser A, Fernandez M, Fernández N, García EA, ... & Hardisty AR (2018) Building essential biodiversity variables (EBVs) of species distribution and abundance at a global scale. Biological Reviews 93, 600-625.

Kleijn D, Raemakers I (2008) A retrospective analysis of pollen host plant use by stable and declining bumble bee species. Ecology 89, 1811–1823.

Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein AM, ... Potts SG (2015) Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 6:7414

Kuldna P, Peterson K, Poltimäe H, Luig J (2009) An application of DPSIR framework to identify issues of pollinator loss. Ecological Economics 69, 32–42.

Laikre L, Hoban S, Bruford MW, Segelbacher G, Allendorf FW, Gajardo G, González Rodríguez A, Hedrick PW, Heuertz M, Hohenlohe PA, Jaffé R, Johannesson K, Liggins L, MacDonald AJ, Orozco-terWengel P, Reusch TBH, Rodríguez-Correa H, Russo I-RM, Ryman N, Vernesi C (2020) Post-2020 goals overlook genetic diversity. Science 367, 1083-1085.

Lindenmayer DB, Likens GE (2010) The science and application of ecological monitoring. Biological Conservation 143, 1317–1328.

Mallinger RE, Gratton C (2015) Species richness of wild bees, but not the use of managed honeybees, increases fruit set of a pollinator-dependent crop. Journal of applied Ecology 52, 323–330.

Martins KT, Gonzalez A & Lechowicz MJ (2015) Pollination services are mediated by bee functional diversity and landscape context. Agriculture, Ecosystems and Environment 200, 12–20.

Maxim L, Spangenberg JH, O'Connor M (2009) An analysis of risks for biodiversity under the DPSIR framework. Ecological Economics 69, 12–23.

Nichols JD, Williams BK (2006) Monitoring for conservation. Trends in Ecology & Evolution 21, 668–673.

Possingham HP, Fuller RA & Joseph LN (2012) Choosing among long-term ecological monitoring programs and knowing when to stop. In: Design and analysis of long-term ecological monitoring studies. Edited by Gitzen RA, Millspaugh JJ, Cooper AB & Licht DS, Cambridge: Cambridge University Press, 498–508.

Potts SG, Biesmeijer JC, Kreme C, Neumann P, Schweiger O & Kunin WE (2010) Global pollinator declines: trends, impacts and drivers. Trends in Ecology & Evolution, 25, 345–353.

Powney GD, Carvell C, Edwards M, Morris RKA, Roy HE, Woodcock BA & Isaac NJB (2019) Widespread losses of pollinating insects in Britain. Nature Communications 10, 1018. doi:10.1038/s41467-019-08974-9

Reynolds JH, Knutson MG, Newman KB et al. (2016) A road map for designing and implementing a biological monitoring program. Environmental Monitoring and Assessment 188, 399.

Riedel S, Meier E, Buholzer S, Herzog F, Indermaur A, Lüscher G, Walter T, Winizki J, Hofer G, Ecker K & Ginzler C (2018) ALL-EMA Methodology Report Agricultural Species and Habitats. Agroscope Science 57, 1–32.

Sapir Y, Dorchin A & Mandelik Y (2015) Indicators of pollinator decline and pollen limitation. In: Armon R, Hänninen O (eds) Environmental Indicators. Springer, Dordrecht, 103–115.

Soroye P, Newbold T, Kerr J (2020) Climate change contributes to widespread declines among bumble bees across continents. Science 367, 685–688.

Spangenberg JH, Martinez-Alier J, Omann I, Monterroso I, Binimelis R (2009) The DPSIR scheme for analysing biodiversity loss and developing preservation strategies. Ecological Economics 69, 9–11.

Stavert JR, Liñán-Cembrano G, Beggs JR, Howlett BG, Pattemore DE & Bartomeus I (2016) Hairiness: the missing link between pollinators and pollination. e2779. PeerJ. 4. https://doi.org/10.7717/peerj.2779

Van der Meij T, Van Strien AJ, Haysom KA, Dekker J, Russ J, Biala K, Bihari Z, Jansen E, Langton S, Kurali A & Limpens H (2015) Return of the bats? A prototype indicator of trends in European bat populations in underground hibernacula. Mammalian Biology 80, 170–177.

Van Strien AJ, Soldaat LL & Gregory RD (2012) Desirable mathematical properties of indicators for biodiversity change. Ecological indicators 14, 202–208.

Van Swaay CAM, Dennis EB, Schmucki R, Sevilleja CG, Balalaikins M, Botham M, ... & Roy DB (2019) The EU Butterfly Indicator for Grassland species: 1990–2017: Technical Report. Butterfly Conservation Europe & ABLE/eBMS (www.butterfly-monitoring.net)

Vanbergen AJ, Heard MS, Breeze T, Potts SG & Hanley N (2014) Status and value of pollinators and pollination services - A report for the Department for Environment, Food and Rural Affairs (Defra UK) Contract number: PH0514.

Warzecha D, Diekötter T, Wolters V & Jauker F (2018) Attractiveness of wildflower mixtures for wild bees and hoverflies depends on some key plant species. Journal of Insect Conservation and Diversity 11, 32– 41.

Winfree R, Kremen C (2009) Are ecosystem services stabilized by differences among species? A test using crop pollination. Proceedings of the Royal Society B: Biological Sciences 276, 229–237.

Winfree, R., W. Fox, J., Williams, N. M., Reilly, J. R., & Cariveau, D. P. (2015). Abundance of common species, not species richness, drives delivery of a real-world ecosystem service. Ecology letters, 18(7), 626–635.

Wintle BA, Runge Mc & Bekessy SA (2010) Allocating monitoring effort in the face of unknown unknowns. Ecology Letters 13, 1325–1337.

Wood TJ, Gibbs J, Graham KK & Isaacs R (2019) Narrow pollen diets are associated with declining Midwestern bumble bee species. Ecology 100(6), e02697

Appendices

Appendix 6.1: Integrated model structure

We assume, for simplicity, that each species' data would be modelled separately. However, it would be possible, and may even be desirable, to fit a single model across all species.

The data entering each species' model represent observations at individual sampling events. By integrating the two data sources, we treat each as a separate realisation of some unknown state variable that represents species abundance. Statistical models of this sort are known as "state-space" models.

Transect counts:

- Latitude & Longitude of the grid cell
- Trap ID within grid cell
- Date of the sampling event
- Species identity
- Count
- Possible Metadata: weather on the day, contextual information about the density of flowers surrounding the transect route, CORINE habitat class etc. etc.

Pan trap:

- Latitude & Longitude of the grid cell
- Trap ID within grid cell
- Date of the sampling event
- Species identity
- Possible Metadata: weather on the day, contextual information about the density of flowers surrounding the trap, CORINE habitat class etc. etc.

Integrating transect counts with presence-absence data from pan traps is conceptually straightforward if we conceptualise the state variable as a Poisson point process, whose intensity varies in space. The intensity of this point process, λ, can be thought of as the expected number of organisms per unit area, and is therefore directly related to species' abundance. The two datasets (transect counts and presence-absence from pan traps) can be thought of as independent but imperfect realisations of this intensity surface (Figure 1).

The model structure follows Bowler et al. (2019), who presented a model integrating transect counts and presence-absence data (from camera traps). They took advantage of the fact that the probability of occupancy (i.e. that the species is truly present on a site), Ψ, can be defined as the probability that abundance is greater than zero. In point-process formulation:

$$\psi = 1 - \mathrm{e}^\wedge(-\lambda) \qquad (1)$$

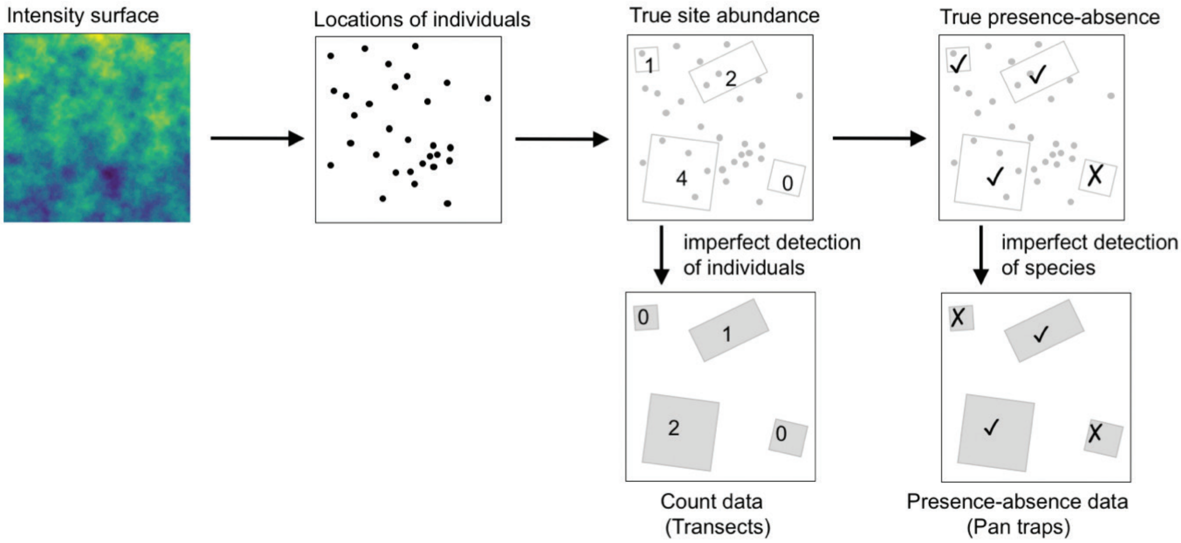
Rearranging this equation and logging both sites we get

$$\log\left(-\log_{i}(1-\Psi)\right)=\log(\lambda) \quad (2)$$

The left-hand side of equation 2 is known as the 'complementary log link', or cloglog for short. Equation 2 proves that occurrence and abundance can be modelled together. Based on this insight, we can model transect counts and pan trap data using generalised linear models. Specifically, for the transect counts, the number of organisms observed, Nijt, on site i during sampling event j in year t can be modelled as a Poisson random variable: whose mean is equal to the intensity of the point process, λ_it, modified by a smooth function, f, of the date, Dj,, to account for seasonal effects[56]:

$$N \text{ ijt } \sim \text{ Poisson } (\lambda \text{ it } + f(D;)\ldots) \quad (3)$$

Figure 1. Conceptual model linking presence-absence data and count data to the intensity of a Poisson point process. Redrawn from Isaac et al. (2020).



We might also include modifiers to account for weather on the day and contextual information about the density of flowers surrounding the transect route (these are represented by dots in equation 3). We might also include an observation-level term if the counts were overdispersed.

The true occupancy (presence-absence) state, z_{it}, is a Bernoulli random variable, the expected mean of which is directly related to the intensity:

$$z_{it} \sim \text{ Bernoulli } \left(\psi_{it}\right) \quad (4)$$

$$\text{clog}\log\left(\psi_{it}\right)=\log\left(\lambda_{it}\right) \quad (5)$$

The pan trap data can be modelled as a realisation of this occupancy state. Observations, y_{ijkt}, at pan trap station *k* are a Bernoulli random variable that is conditional on occupancy and detection, p_{ijkt}:

$$y_{ijkt} \sim \text{ Bernoulli } \left(z_{it} \cdot p_{ijkt}\right) \quad (6)$$

56 For simplicity this seasonal effect is presented as constant across sites: in reality it would be wise to allow this seasonality to vary with latitude and longitude.

$$\operatorname{logit}\left(p_{ijkt}\right)=b_{p}+cV_{k}+f\left(D_{j}\right) \tag{7}$$

In which V_k is a trap-level covariate, such as the density of flowers in the vicinity of the pan trap[57]. Note that the seasonal effect term, $f(D_j)$, is shared with the transect submodel (equation 3).

Our state variable, the intensity of the point process, is a linear function of site and year effects:

$$\log\left(\lambda_{it}\right)=b_{0}+b_{t}+s\left(\mathrm{X}_{i},\mathrm{Y}_{i}\right) \tag{8}$$

Where b_0 is the intercept, b_t is a year effect[58], $s(x_i,y_i)$ is a smooth function of latitude (Y_i) and longitude (X_i). The dots ("....") represent other covariates that we might choose to include, such as climate, land cover class and country.

The model above could be fitted in the BUGS language (Bowler et al. 2019) or INLA (Illian et al. 2013) following Dambly et al. (2019). Pros and cons of these approaches are discussed in Isaac et al. (2020).

From Species Models to indicators

Estimates of λ_{it} for each species would be extracted into a separate database, accompanied by appropriate measures of uncertainty (e.g. 95% credible intervals) representing a three-dimensional species-site-time EBV cube. As described above, it would be straightforward to extract summaries along either the species or site dimension of the EBV cube (Figure 6.6).

Option 3A: The species' geometric mean abundance is a standard indicandum in biodiversity indicators, such the Farmland Bird Index. To derive this, first calculate the species' mean abundance across sites, λ_t:

$$\lambda_{st}=\frac{\sum_{i=1}^{n.site}\lambda_{ist}}{n_{site}} \tag{8}$$

The multispecies indicator, I_t is the geometric mean across species:

$$\log\left(I_{t}^{sp}\right)=\frac{\sum_{s=1}^{n\cdot sp}\log\left(\lambda_{st}\right)}{n_{sp}} \tag{9}$$

expressed relative to the value in some baseline value (e.g. 100 in the starting year).

Data on species' traits or functional role could be used to weight or stratify species within the multispecies indicator.

Option 3B: An alternative indicandum might be the (change in) local alpha diversity, calculated as Shannon's entropy for each site:

$$H_{it}=-\sum\left(P_{st}\cdot\log\left(P_{st}\right)\right) \tag{10}$$

where

$$P_{st}^{m}=\frac{\lambda_{st}}{\sum_{s=1}^{n.sp}\lambda_{st}} \tag{11}$$

57 In this formulation, pan traps within sites are treated as replicates for estimating occupancy at the level of the grid cell. It would be possible to specify an alternative formulation in which occupancy was modelled separately for each trap, as an independent realisation of the point process. The most appropriate choice depends on the spatial grain of the grid cell, the distance between pan trap locations and the spatial scale at which the organisms move around in the environment.

58 This formulation is simple and limiting. See 'extensions' for more details

An indicator measuring change in alpha diversity could be a simple arithmetic mean across sites:

$$I_t^{\text{site}} = \frac{\sum_{i=1}^{n.site} H_{it}}{n_{\text{site}}} \qquad (12)$$

expressed relative to the value in some baseline value (e.g. 100 in the starting year). However, given that we expect not all transect observations will be identified to species level, the calculation of functional community metrics could be potentially misleading.

The formulation above assumes that the trend in each species' is the same across the entire site network. An obvious extension would be to allow trends to vary in space. From a fully spatio-temporal model it would be trivial to stratify equation 8 by member state or by landcover class. Similarly, question-driven indicators could be derived by sub-setting the sites within the Natura 2000 network, or those subject to CAP subsidy.

The formulation above could be extended to include unstructured occurrence records (Powney et al. 2019) as an additional data source.

References

Bowler DE, Nilsen EB, Bischof R, O'Hara RB, Yu TT, Oo T, ... & Linnell JDC (2019) Integrating data from different survey types for population monitoring of an endangered species: the case of the Eld's deer. Scientific Reports. doi:10.1038/s41598-019-44075-9

Dambly L, O'Hara B, & Golding N (2019). oharar/IM_warbler: Integrated analysis of black-throated blue warbler data from PA, USA. doi:10.5281/ZENODO.3363936 (August 8)

Illian JB, Martino S, Sørbye SH, Gallego-Fernández JB, Zunzunegui M, Esquivias MP & Travis JMJ (2013) Fitting complex ecological point process models with integrated nested Laplace approximation. Methods in Ecology and Evolution 4, 305–315.

Isaac NJB, Jarzyna MA, Keil P, Dambly LI, Boersch-Supan PH, Browning E, ... & O'Hara RB (2020) Data Integration for Large-Scale Models of Species Distributions. Trends in Ecology & Evolution, 0(0). doi:10.1016/J.TREE.2019.08.006

Powney GD, Carvell C, Edwards M, Morris RKA, Roy HE, Woodcock BA & Isaac NJB (2019) Widespread losses of pollinating insects in Britain. Nature Communications 10, 1018. doi:10.1038/s41467-019-08974-9

Appendix 6.2: State Indicator application tests

Here are presented some illustrative examples of the application of the proposed state indicator approaches using real datasets. We provide examples for approaches 1 and 2 from table 1 (either pan traps or transects data).

Key information of the datasets used for the tests:

Approach 1: Trends in occupancy/richness

1A): Trend in average occupancy of species (pan traps)

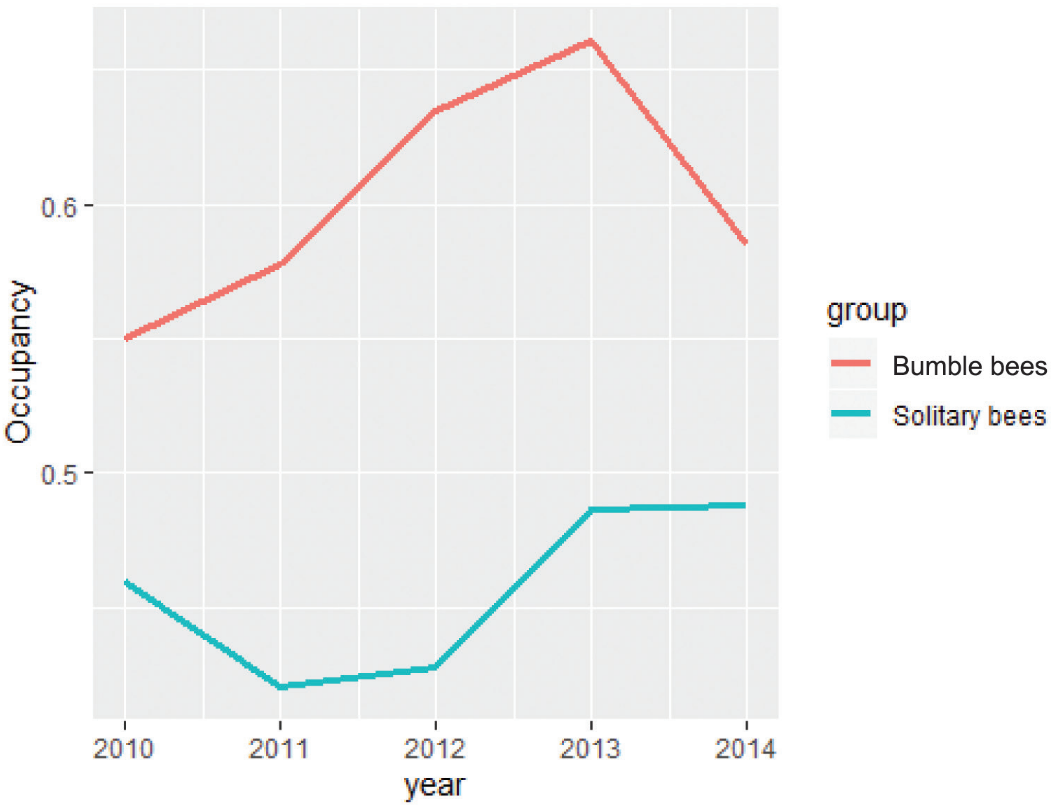
Summing across sites, a table of the estimated number (or proportion) of sites occupied by each species in each year is calculated. The geometric mean occupancy for different pollinator groups can be then computed. Occupancy models were implemented in R statistical software version 5.3.1 (R Core Team, 2018), using "Sparta" package version 0.2.0. Sparta provides a range of tools for analysing trends in species occurrence data and is based on the work presented in Isaac et al. (2014). Resulting graphs show geometric mean occupancy trends for bumble bees and solitary bees (Fig. 1) and mean occupancy trends for different genera of solitary bees (Fig. 2). These are preliminary results and do not represent definitive model outputs.

1B): Trend in average species richness of sites (pan traps)

Summing across species, a table of estimated species richness at each site in each year. The geometric mean of species richness across sites is calculated as an indicator of pollinator presence. Resulting graphs show average species richness per site (16 traps per site, Fig. 3), and geometric mean of species richness across the 6 sites, for bumble bees and solitary bees (Fig. 4).

Dataset provider	Taxa	Method	Number of samples	Repetitions within each year	Years of sampling	Region/ Country	Indicator approach
Oliver Schweiger	wild bees: bumble bees (21 species) and solitary bees (253 species)	pan traps	16 Pan traps x 6 sites (4x4 km each site)	6; late spring-early summer (3) and late summer (3)	2010–2014	Saxony-Anhalt, Germany	1A & 1B
Ignasi Bartomeus	Bumble bees, solitary bees, hoverflies, butterflies and honey bees	transects (100 m/30 m)	16 sites	7–8 rounds per year	2015–2016	Guadalquivir Valley, Southern Spain	2
Ante Vujić	Hoverflies	transects	12 sites	1 (mostly) or 2	2015–2019	Serbia	2

Fig. 1. Trend lines show average occupancy of 1 km x 1 km sites (trap level) across all modelled solitary bees (n= 253, blue) and bumble bees (n= 21, red) species.



Approach 2: Observed abundance of species groups

2): Trend in total abundance of pollinator groups (transects)

Averaging across sites produces a 'flat' table of abundance times-series for each group, from which an 'abundance indicator' would be calculated as the geometric mean across groups. Resulting graphs show average abundance of different pollinator groups across sites in Southern Spain (Fig. 5) and the geometric mean across pollinator groups (Fig. 6).

Additional results from hoverfly transect data collected in Serbia showed average abundance across sampling sites for different hoverfly dietary groups (Fig. 7) and geometric mean across all hoverfly species (Fig. 8).

Fig. 2. Trend lines show average occupancy of 1 km x 1 km sites (trap level) for different solitary bee genera.

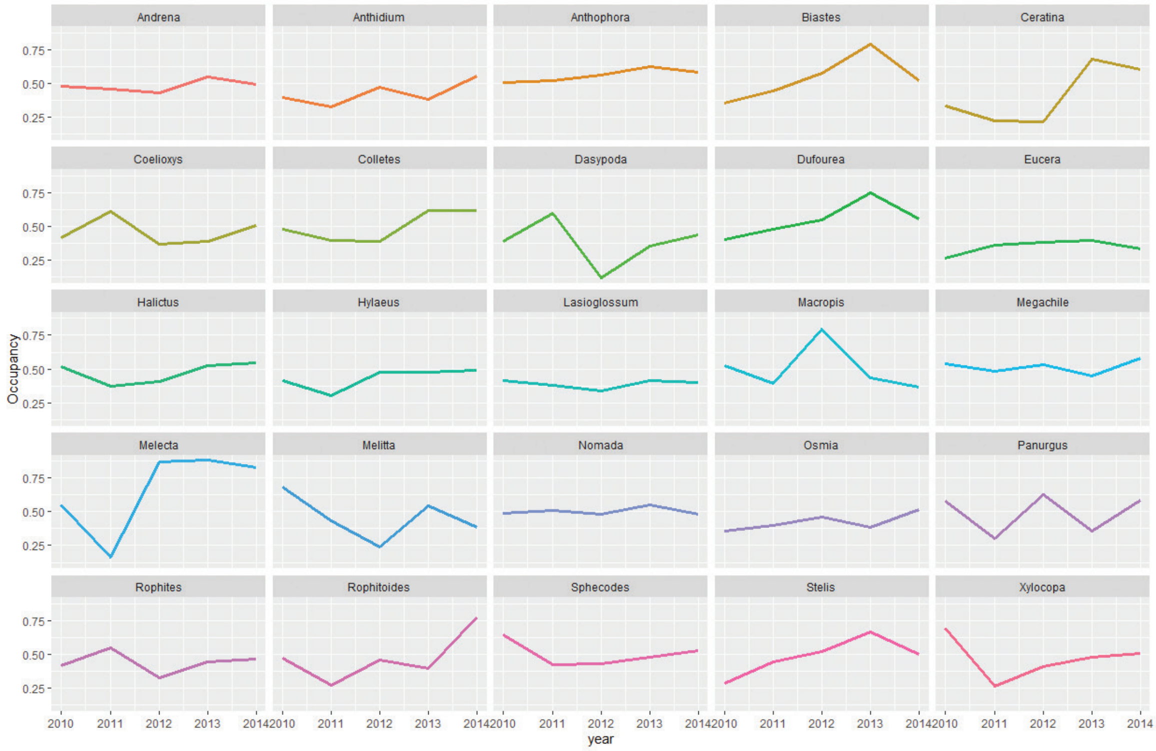


Fig. 3. Trend in species richness for each site, for bumble bees and solitary bees respectively.

Fig. 4. Trend in geometric mean of species richness across the 6 study sites for bumble bees and solitary bees respectively.

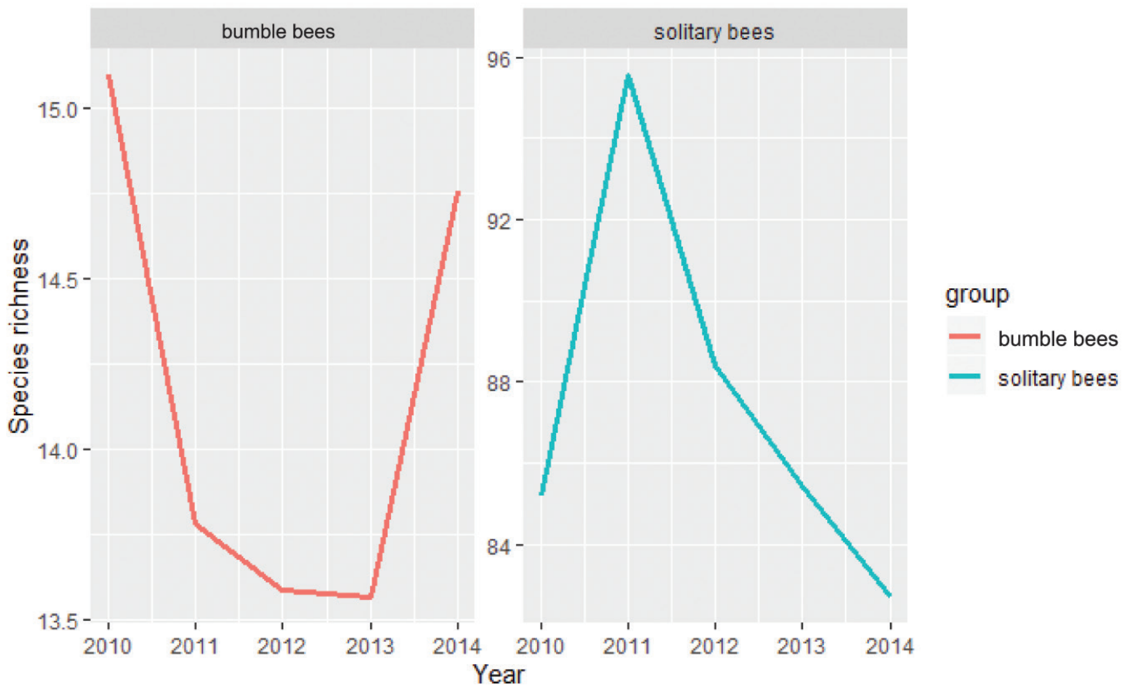


Fig. 5. Trend in mean of species abundance across sites for different pollinator groups (BB: bumble bees, HB: honey bees, HF: hoverflies and SB: solitary bees)

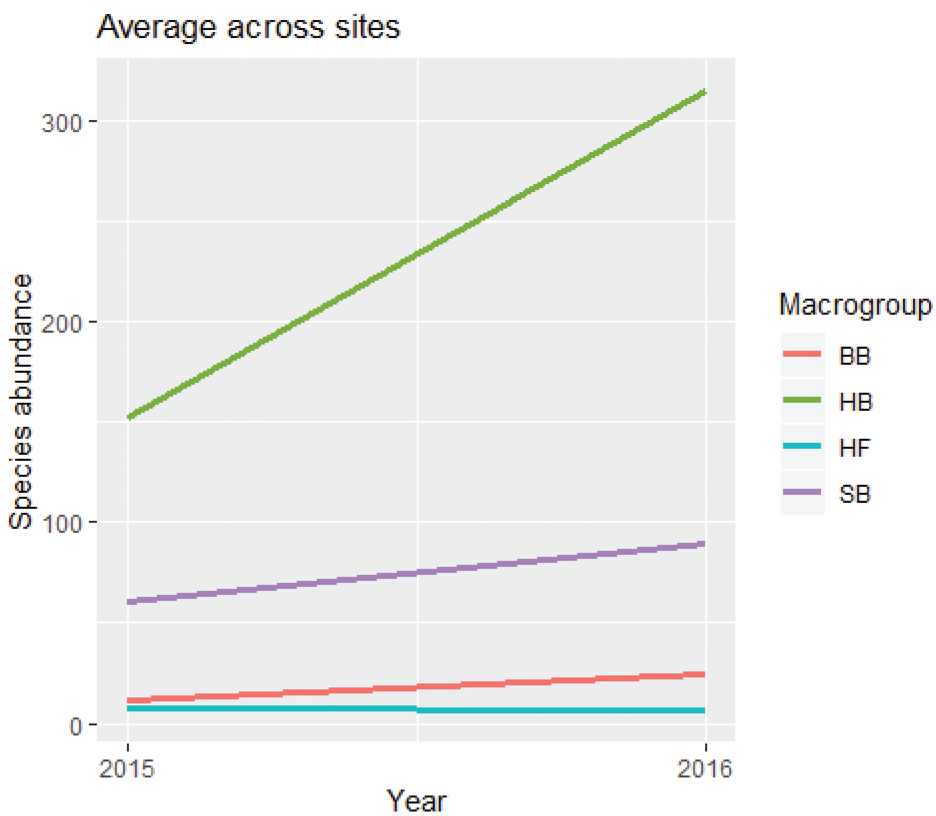


Fig. 6. Trend in geometric mean of species abundance across all pollinator groups

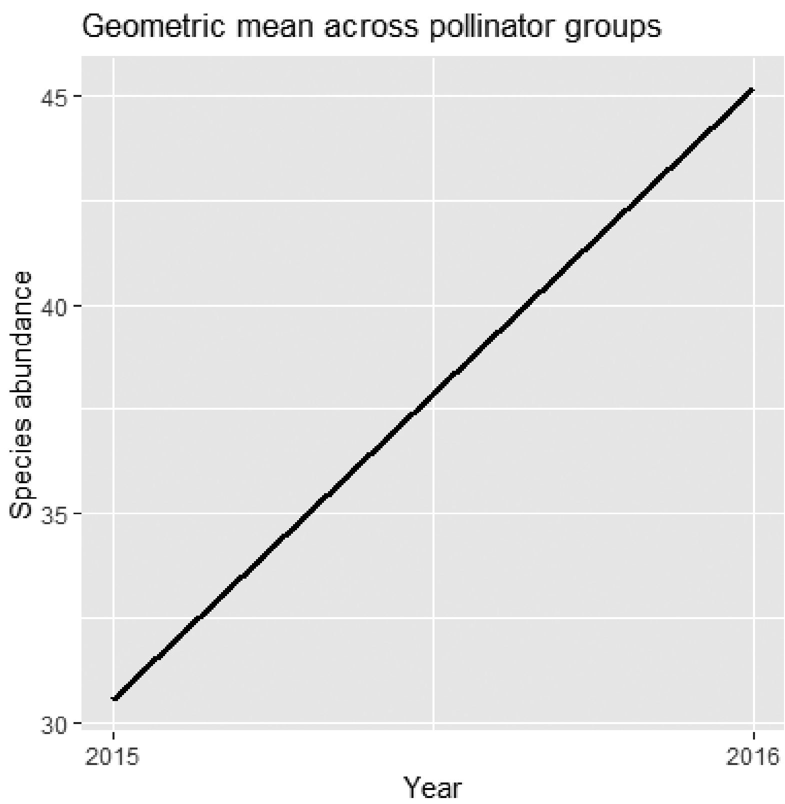


Fig. 7. Trend in mean of species abundance across sites for different hoverfly dietary groups.

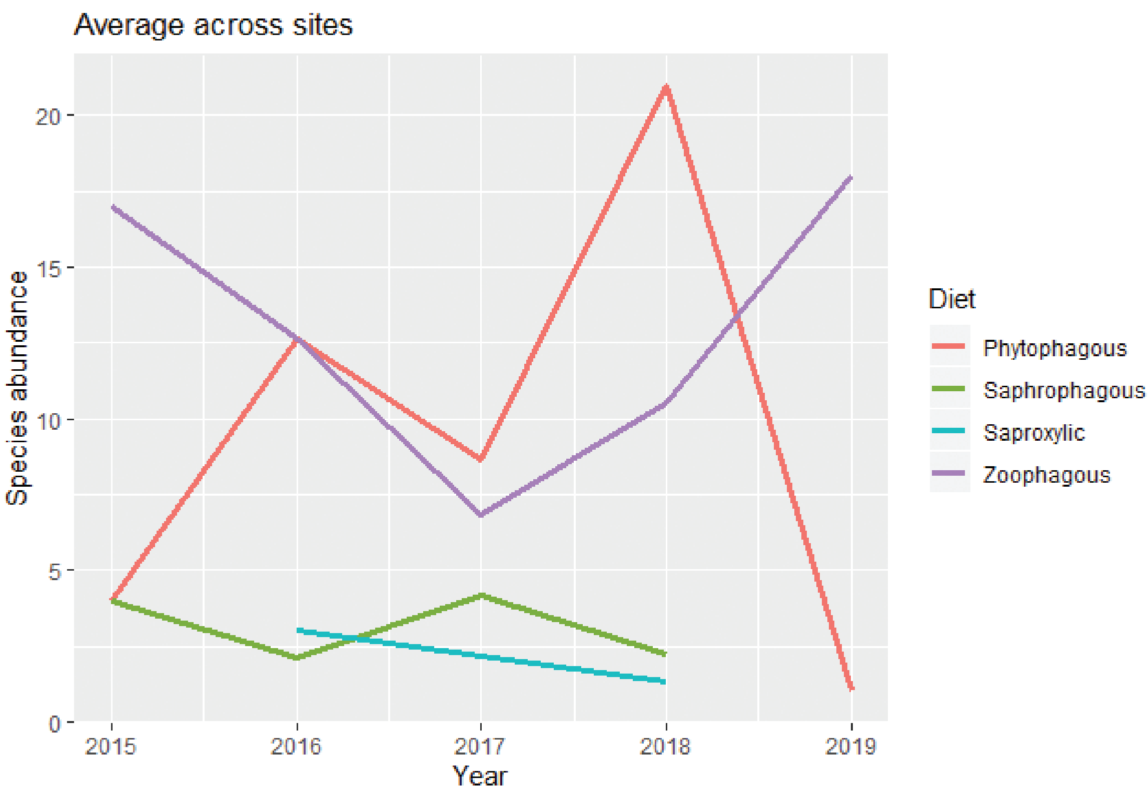
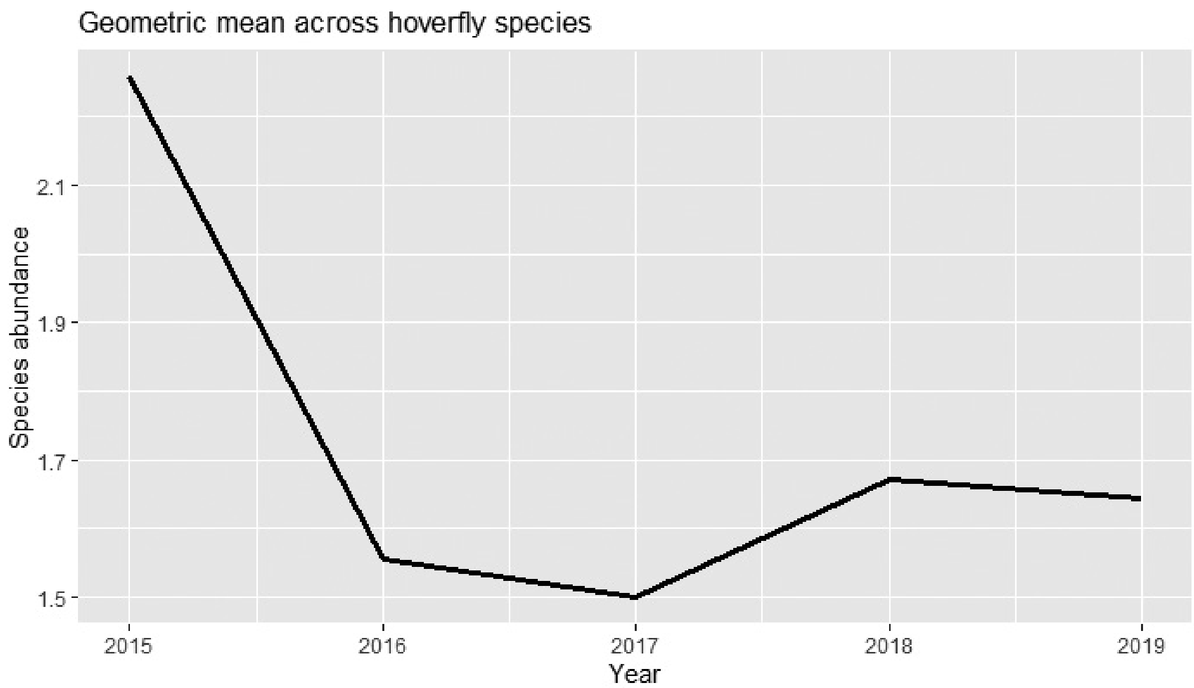


Fig. 8. Trend in geometric mean of species abundance across all hoverfly species.



References

Isaac NJB, van Strien AJ, August TA, de Zeeuw MP, Roy DB (2014) Statistics for citizen science: Extracting signals of change from noisy ecological data. Methods Ecol. Evol. 5, 1052–1060. doi:10.1111/2041-210X.12254

R Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

7 Taxonomic and Data Support for the EU Pollinator Monitoring Scheme

This chapter provides an overview on the current taxonomic expertise in EU Member States and the UK (which was still a Member State when this report was started) on wild bees, butterflies and hoverflies, including the availability of taxonomic resources, such as field guides, identification keys, online tools and DNA barcodes (section 7.1). This is used as the basis for a gap analysis to inform on proposed pathways to close the taxonomic gap between the current and required levels of species identification capability anticipated for the European pollinator monitoring scheme (section 7.2). Different pathways and options for data capture, validation, analysis and storage are assessed in section 7.3.

7.1 Assessment of current taxonomic expertise and resources on key pollinator taxa in Europe

7.1.1 Approach to assessing current taxonomic expertise

Experts on three pollinator taxa (wild bees, butterflies and hoverflies) from each European Member State and the UK were contacted to obtain information on the current taxonomic capacities. The following questions were asked:

General quality of taxonomic knowledge on the respective pollinator group in the country concerned compared to other European countries (poor, medium, good, very good)? (expert opinion)

- Availability of a checklist (with reference or link)?
- Availability of a field guide (with reference or link)?
- Availability of online identification (ID) tools (with reference or link)?
- Availability of an atlas (with reference or link)?
- Availability of an online atlas or recording scheme (with link)?

Bombus lapidarius & *B. pascuorum*, John Breen

- Availability of handbook or ID keys (with reference or link)?
- Availability of a national red list (with reference or link)?
- Availability of internet fora or discussion groups?
- How many species are DNA barcoded?
- How many experts for this taxonomic group exist in the respective country?
- Are there any regular meetings or organisations?

Based upon this questionnaire, two maps were prepared to obtain an overview on the current taxonomic capacity: (i) a map based upon the expert opinion as stated in the first question, and (ii) a map based upon the availability of taxonomic resources (based upon the key question: Which resources would be available for an amateur to start working on the respective pollinator group in each country?).

7.1.2 Wild bees (Anthophila)

Around 2,050 wild bee species have been reported from Europe (Rasmont et al. 2017, section 3.1.1). Many solitary bee species are highly specialised in food (pollen) of their larvae. In addition, they often require special nesting sites, such as bare ground, steep or sloping ground, dead wood or pithy stems (Potts et al. 2005).

7.1.2.1 Expert opinion on the taxonomic knowledge in each country

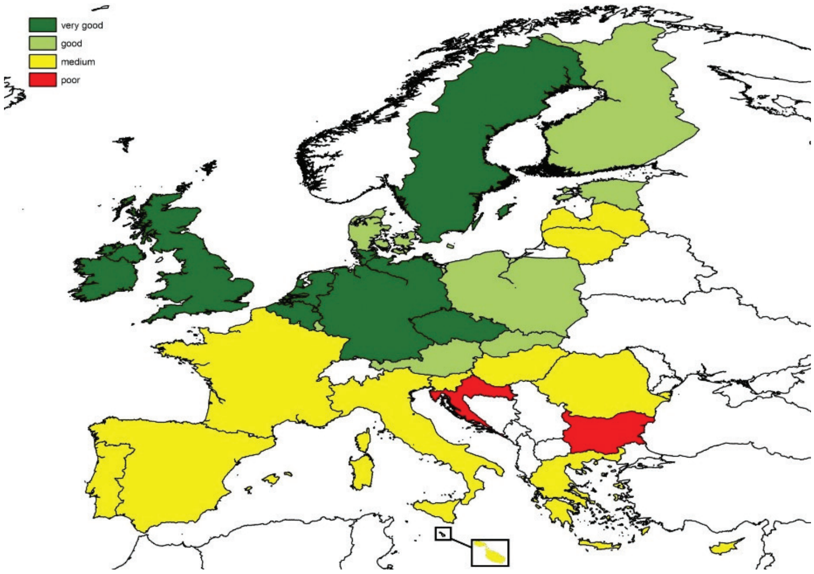
The following experts provided information on wild bees in each country:

Austria: Zettel Herbert
Belgium: Denis Michez
Bulgaria: Toshko Ljubomirov
Croatia: Andrej Gogala
Cyprus: Menelaos Stavrinides
Czech Republic: Petr Bogusch; Jakub Straka
Denmark: Claus Rasmussen
Estonia: Marika Mänd
Finland: Juho P.T. Paukkunen
France: Benoit Geslin
Germany: Michael Kuhlmann
Greece: Theodora Petanidou
Hungary: Miklós Sárospataki; Anikó Kovács-Hostyánszki
Ireland: Robert Paxton; Jane Stout
Italy: Marino Quaranta
Latvia: Jānis Gailis
Lithuania: Eduardas Budrys
Luxembourg: Nico Schneider
Malta: Mario V, Balzan
Netherlands: Menno Reemer
Poland: Józef Banaszak
Portugal: David Baldock
Romania: Alexandra Popa
Slovakia: Peter Sima
Slovenia: Andrej Gogala
Spain: Francisco Javier Ortiz Sanchez; Ignasi Bartomeus; Jordi Bosch Gras
Sweden: Karin Ahrné
UK: Stuart Roberts

Full responses country by country are provided in Appendix 7.1.

The map below (Figure 7.1) illustrates the taxonomic knowledge of wild bees in the EU27 countries and the UK according to expert opinions (see question 1 in section 7.1.1). Generally, taxonomic knowledge is rated higher in northwest and central Europe than in the south and east.

Figure 7.1. Expert opinion on the taxonomic knowledge on wild bees in the member states of the European Union and the UK (colour codes from red = poor to dark green = very good).



7.1.2.2 Taxonomic resources

Checklists

Complete checklists exist for nearly all European countries, except for Croatia. A European checklist is included in the European Red List of bees (Nieto et al. 2014) with an update published in 2017 (Rasmont et al. 2017). In most countries, the checklists were published during the last 10 to 25 years. For four countries, new checklists are currently in preparation (Bulgaria, Germany, Greece and Italy).

Field guides

Good field guides mainly exist in northwest and central Europe. The field guide to Great Britain and Ireland by Falk & Lewington (2015) has been translated into Dutch (Falk & Lewington 2017) and is also used in other northern European countries. For the Netherlands, a new field guide by van Breugel (2019) is available. Other field guides exist for the Czech Republic (Macek 2017), Finland (Söderman & Leinonen 2003), Slovakia (Pavelka & Smetana 2000), Slovenia (Gogala 2014) and Spain (Aguado Martín et al. 2015). For Italy, keys to the genera by Quaranta (2019) are available. For some countries, special books for bumble bees exist, e.g. Austria and Germany (Gokcezade et al. 2017), Finland (Parkkinen et al. 2018), Lithuania (Tamutis et al. 2010), the Netherlands (Smit et al. 2018), and Sweden (Holmström 2007, Mossberg & Cederberg 2012, Söderström 2013).

Handbooks and identification keys

A new book by Michez et al. (2019) provides identification keys to all European bee genera and also provides a lot of information on many species. For Austria and Germany, extensive identification keys are available (e.g. Scheuchl 2000, 2006; Schmid-Egger & Scheuchl 1997), which are widely used in adjacent countries. Similarly, the Swiss keys of the Fauna Helvetica (Amiet et al. 1999, 2001, 2004, 2007, 2010, 2017) are used in many European countries. For Finland, several old identification keys exist in addition to the new field guides (e.g. Pekkarinen & Teräs 1977). In France, a book by Berland (1999) is available. A new handbook on the biology and ecology of all German species has recently been published (Westrich 2019). The publication of a handbook is also planned for Greece. In Hungary, older keys by Móczár (1957, 1958 and 1960) are available (only the Andrenidae are missing). For Ireland and the UK, a handbook by Else & Edwards (2018) exists. Dichotomous keys have also been published in the Netherlands (Nieuwenhuijsen & Peeters 2016); the atlas by Peeters et al. (2012) also contains a key to the genera. For Romania, a handbook for the Megachilidae and Anthophoridae has been published (Ban-Calefariu 2009). Furthermore, older

Anthidium manicatum, Liam Lysaght

keys to the Apinae (Knechtel 1955), Anthophorinae (Iuga 1958), and cuckoo bumble bees (Tomozei 2000) exist. For Slovakia, a book by Pavelka & Smetana (2000) is available. A partial handbook is available for Spain (Ortiz-Sánchez & Gellego 2004). For Sweden, a key to the genus *Hylaeus* is available (Holmström 2014), and new identification keys to other genera are currently in preparation. It is noticeable that many identification keys for bees are scattered across several volumes of handbooks or sometimes only available for some families. Some important keys have been published privately and are difficult to obtain.

Online ID tools

Online identification tools are available in the Netherlands[1], Ireland[2] and Sweden[3]. The latter are also used in Finland. In Estonia, an online key to the bumble bee and a reduced version of this key exist[4]. Online ID tools are also planned in France, but lack funding (Perrard in prep.). Numerous identification keys can also be downloaded from Atlas Hymenoptera[5], where photos of many species are also available. A European online key is also available[6].

1 https://determineren.nederlandse soorten.nl/linnaeus_ng/app/views/matrixkey/index.php?p=tuinbijen
2 https://pollinators.ie/ record-pollinators/id-guides/
3 https://artfakta.se/artbestamning/taxon/apiformes-2002991-fullbildade-bin/artnyckel
4 https://pmk.agri.ee/sites/default/files/uploads/sites/2/2017/01/Estonian-bumblebees.pdf; http://www.looduskalender.ee/suuredpildid/Kimalaste-varvikoodid.pdf
5 http://www.atlashymenoptera.net/
6 https://keys.lucidcentral.org/search/key-to-european-genera-of-bees-anthophila/

Sphecodes spec., Axel Hochkirch

Atlases

Atlases have been published for several countries, such as the Czech Republic (Macek 2017), Denmark (Rasmussen et al. 2016), Finland (Söderman & Leinonen 2003), the British Isles (Else & Edwards 2018), Lithuania (Monsevičius 1995), the Netherlands (Peeters et al. 2012), and Slovenia (Gogala 2014). For Hungary, an atlas for the bumble bees is available (Sárospataki et al. 2005). Provincial records are available for Portugal. For Slovenia, only a partial atlas is available. In Germany, atlases have been published for some federal states. The Austrian atlas data is privately stored (ZOBODAT[7]). In Luxembourg, an atlas is in preparation.

Online atlases or recording schemes

The website Atlas Hymenoptera, provides distribution information for all European bee species. In Belgium, the online recording scheme[8] is widely used and an atlas project is available online[9]. Online recording schemes also exist in Estonia[10], Finland[11], Latvia[12], Luxembourg[13], Netherlands[14] and Sweden[15] and UK[16]. In Malta, a mobile App to record the ten most common bee species has been developed. An online atlas is also available for France[17], Germany[18], Ireland[19] and UK[20]. In Finland, a national bumble bee recording scheme (PÖLYHYÖTY[21]) has recently started. A bumble bee recording scheme is also available in Sweden[22].

7 https://www.zobodat.at/
8 waarnemingen.be
9 http://www.atlashymenoptera.net/liste_them.asp?them=Belgium
10 https://elurikkus.ee/en
11 laji.fi
12 https://dabasdati.lv/en
13 mdata.mnhn.lu
14 waarneming.nl
15 artfakta.se; www.artportalen.se
16 www.nbnatlas.org
17 http://www.atlas hymenoptera.net/liste_them.asp?them=France
18 http://www.wild bienen-kataster.de/
19 https://maps.biodiversityireland.ie/
20 https://www.bwars. com/content/bwars-maps-and-species-concepts
21 https://www.syke.fi/fi-FI/Tutkimus__kehittaminen/ Tutkimus_ja_kehittamishankkeet/Hankkeet/Suomen_polyttajahyonteiskantojen_tila_seuranta_ja_hyonteispolytyksen_taloudellinen_merkitys_maataloudelle/Suomen_polyttajahyonteiskantojen_tila_se(49617)
22 https://www.slu.se/en/ Collaborative-Centres-and-Projects/nils/

Monitoring

Transect based monitoring schemes for bumble bees have already been established in some European countries. Many of these use a similar methodology to the well-established European butterfly monitoring scheme. An Irish scheme was started in 2011, and currently has >100 transects. In Finland, a scheme was piloted across ~90 transects in 2019. In Sweden, bumble bees have been monitored along transects in meadows and pastures since 2006 within the National Inventory of Landscapes in Sweden. An Estonian bumble bee monitoring scheme was started in 2006 and focuses solely on agricultural areas.

National Red Lists

For wild bees, a European Red List is available (Nieto et al. 2014). National Red Lists for wild bees exist in Belgium (Leclercq et al. 1980, a new one is in press), the Czech Republic (Hejda et al. 2017), Denmark (Wind & Phil 2010, Madsen 2019), Estonia[23], Finland (Paukkunen et al. 2019), Germany (Westrich et al. 2011), Ireland (Fitzpatrick et al. 2006), Italy (Quaranta et al. 2018), Latvia (Spuris 1998), Lithuania (Rašomavičius 2007), Netherlands (Reemer 2018), Poland (Głowaciński & Nowacki 2009), Slovakia (Belakova 1996), Spain (Verdú & Galante 2006), Sweden (SLU Artdatabanken 2020) and the UK (Falk 1991, a new one is in press). In Hungary, a national Red List for bumble bees is available (Sárospataki et al. 2005). A national Red List is also under development in France, and an unpublished one exists for Greece.

Internet fora or discussion groups

Several experts have reported that internet fora exist in their countries: Estonia[24], Czech Republic[25], Denmark[26], Finland[27], Hungary[28], Ireland[29], Italy[30], Latvia[31], Netherlands[32], Romania[33], Spain[34] and Sweden[35] and UK[36]. International Listservs are also used by European wild bee experts, e.g. International Commission for Plant-Pollinator Relations[37] and Pollination and Palynology List[38].

DNA-Barcoding

The German online database GBOL[39] lists 504 species barcoded, 121 not collected and 6 collected but not barcoded, yet (accessed 18 Oct 2019). Austria has a Barcode of Life project[40], including two projects on wild bees. For Belgium, ~250 species and in the Netherlands ~200 barcoded species have been reported by the experts, but it is likely that there is a strong overlap with the German species. Similarly, the Danish expert mentioned ~100 species. Of the 234 bee species known from Finland, 152 have been barcoded successfully in the FinBOL project[41]. The Greek expert reported that ~100 species have been barcoded, while for Ireland all species are covered. In Italy, a barcoding project has just been started. In Malta, barcodes for 44 wild bee species have been compiled. In the UK, 277 species are barcoded (nearly all bee species). Similarly to the other taxa, the information on barcoded species is rather scattered and not readily available as not all barcodes have been published or transmitted to databases.

Availability of experts

The number of wild bee experts is very limited in most countries. In some countries, no wild bee experts are available (e.g. Croatia, Portugal). In many other countries, only one or two wild bee experts exist (e.g. Bulgaria, Cyprus, Greece, Lithuania, Malta, Romania and Slovenia). Up to five experts are available in Finland, Latvia, Luxembourg, Slovakia and Spain. A few countries have

23 https://infoleht.keskkonnainfo.ee/default.aspx?id=-598760291&state=3
24 https://www.facebook.com/groups/kimalased/
25 Facebook groups “Blanokřídlí České republiky” and “Určování bezobratlých”
26 Facebook group “Bier i felten”
27 https://foorumi.laji.fi/; Facebook group https://www.facebook.com/groups/suomenotokat/
28 https://www.facebook.com/groups/613454568726835/
29 https://www.facebook.com/groups/insectsinvertebratesire/
30 Facebook group “Beewatching”; http://www.apiselvatiche.it; http://www.beewatching.it
31 https://dabasdati.lv/en
32 https://forum.waarneming.nl/smf/index.php?board=215.0; Facebook group “Solitaire bijen & hommels”
33 http://www.beesofromania.ro/home-1
34 https://www.biodiversidadvirtual.org/, http://www.anthos.es/
35 Facebook groups “Insekter i Sverige”, “Vilken insekt?” and “vi som gillar bin”
36 Several groups exist, and the most widely used are those managed by BWARS on Facebook (“UK Bees, Wasps and Ants”; https://www.facebook.com/groups/1590641777855221)
37 ICPBR@LISTSERV.UOGUELPH.CA
38 POLPAL-L@LISTSERV.UOGUELPH.CA
39 https://www.bolgermany.de/
40 https://www.abol.ac.at/
41 https://www.finbol.org/

up to ten wild bee experts (e.g. Denmark, Estonia, France, Hungary, Ireland, Italy, Poland and Sweden) and only five countries have more than 10 (Austria, Belgium, Germany, Netherlands and the UK).

Meetings and organisations

A meeting of Czech and Slovak hymenopterists[42] is held each year. An association also exists in Belgium[43]. The Finnish Expert Group on Hymenoptera[44] meets three times per year. In France, the list Apoidea Gallica[45] organises a weekend congress each year; furthermore, there is a research group (POLINECO), which organises a congress with 100 to 150 participants. In Germany, a Hymenopterists' meeting is held biannually in Stuttgart[46]. The main relevant organisation in Ireland is the All-Ireland Pollinator Plan[47], implemented by the National Biodiversity Data Centre; furthermore, an academic research network exists, the Irish Pollinator Research Network[48] that meets once per year. In Italy, CREA is the leading research organisation on bees, which meets every three months; CREA-AA, Bologna, is a permanent venue for courses[49], regularly held several times a year on wild bee taxonomy, melissopalynology, sensory analysis of honey, beekeeping expert and bee pathology. The Sectie Hymenoptera of the Dutch entomological society (NEV) [50] organises several field meetings and symposia every year in the Netherlands. The EIS Kenniscuntrum Insecten also organises meetings sometimes and the Nederland Zoemt[51] project is raising bee awareness among Dutch citizens. In Spain, there is a meeting on the ecology and evolution of flowers and interactions with flower visitors (ECOFLOR)[52]. The Swedish red list committee for Hymenopterans is coordinated by the Species Information Center[53] and has regular meetings. In some countries, special organisations for bumble bees exist, e.g. the Bumblebee monitoring group[54] at the Estonian University of life Sciences. In the UK, there is an annual weekend reunion by the Bees, Wasps and Ants Recording Society (BWARS)[55]. The Society also publishes a twice yearly newsletter. In the UK, the Bumblebee Conservation Trust (BBCT)[56] holds an annual members' day each autumn. BBCT publishes 'Buzzword' several times a year and runs training workshops in bumble bee identification and monitoring. Bees are also discussed at the meetings of general Entomological Societies, such as the Finnish Entomological Society and the Entomological Society of Helsinki, the German Society for basic and applied Entomology[57], the Irish Entomology Meeting[58], the Entomological Society of Latvia[59], the Lithuanian Entomological Society[60], Royal Entomological Society[61] and the Swedish Entomological Society[62].

7.1.2.3 Overall quality of taxonomic resources in each Member State

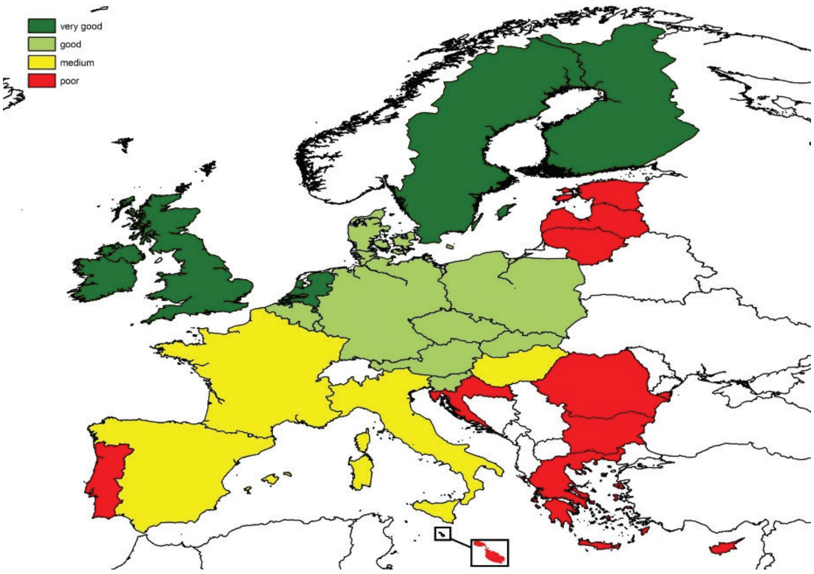
The following map (Figure 7.2) provides an overview on the quality of existing taxonomic resources in each country, including the UK. The map was built based upon the question "which resources would be available for an amateur to start working on the respective pollinator group?" in each country. The colour codes range from red (poor taxonomic resources available, usually a checklist, but no keys, field guides etc.) to very good (high quality field guides or online resources available). There is a general negative relationship between the availability of taxonomic resources and wild bee diversity, which is highest in the Mediterranean.

7.1.3 Butterflies (Papilionoidea)

Butterflies are the most studied insect group in Europe, with 496 species documented (Wiemers et al. 2018). The ecology of butterflies is strongly determined by the food plant of the caterpillars, many of which are highly specialised in diet. In addition, the microclimate is of importance for their habitat affiliation.

42 http://hymenoptera.wz.cz/
43 http://www.srbe-kbve.be/cm/
44 http://pistiaistyoryhma.myspecies.info/
45 http://sapoll.eu/apoidea-gallica/
46 https://naturkundemuseum-bw.de/fileadmin/user_upload/18_hymi_tagung_programm.pdf
47 www.pollinators.ie
48 http://www.ecoevoblog.com/2019/01/22/pollinator-network-2019/
49 https://www.crea.gov.it/en/web/agricoltura-e-ambiente/-/corsi-qualificazione-professionale-api-apicoltura
50 https://www.nev.nl/
51 www.nederlandzoemt.nl
52 https://ecoflor2020.weebly.com/programme.html
53 https://www.artdatabanken.se/
54 https://www.bwars.com/home
55 https://www.bwars.com/home
56 https://www.bumblebeeconservation.org
57 https://www.dgaae.de/de/startseite-dt.html
58 https://www.ringofgullion.org/events/the-2nd-irish-entomology-meeting/
59 http://leb.daba.lv/
60 http://www.entomologai.lt/
61 https://www.royensoc.co.uk/
62 https://www.sef.nu/

Figure 7.2. Availability of taxonomic resources to identify wild bees in the Member States of the European Union and the UK (from red = no or very limited resources available to dark green = numerous or very good identification tools available).



7.1.3.1 Expert opinion on the taxonomic knowledge in each country

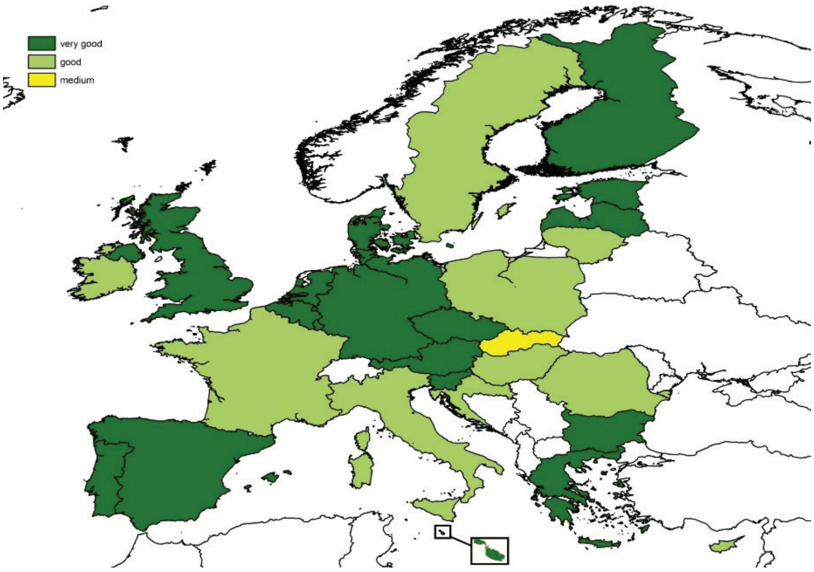
The following experts provided information on butterflies in each country:

Austria: Helmut Höttinger
Belgium: Dirk Maes; Philippe Goffart
Bulgaria: Toshko Ljubomirov
Croatia: Martina Sasic
Cyprus: Elli Tzirkalli
Czech Republic: Alois Pavlíčko
Denmark: Emil Bjerregård
Estonia: Toomas Tammaru
Finland: Mikko Kuussaari
France: Benoît Fontaine
Germany: Josef Settele, Martin Wiemers
Greece: Vassiliki Kati
Hungary: Zsolt Bálint
Ireland: Liam Lysaght
Italy: Simona Bonelli
Latvia: Kristaps Vilks
Lithuania: Dalius Dapkus
Luxembourg: Roland Proess, Xavier Mestdagh
Malta: Louis F. Cassar
Netherlands: Chris van Swaay
Poland: Marcin Sielezniew
Portugal: Patrícia Garcia Pereira
Romania: Mihai Stanescu
Slovakia: Henrik Kalivoda
Slovenia: Rudi Verovnik
Spain: Miguel López Munguira, Constanti Stefanescu
Sweden: Lars Pettersson
UK: David B. Roy

Full responses country by country are provided in Appendix 7.2.

The map below (Figure 7.3) illustrates the taxonomic knowledge in the EU27 countries and the UK based upon expert opinions (see question 1 in section 7.1.1). Generally, taxonomic knowledge is rated very good or good in most countries. Only the Slovakian expert rated it as medium (probably because of the paucity of butterfly experts in the country).

Figure 7.3. Expert opinion on the taxonomic knowledge of butterflies in the Member States of the European Union and the UK (colour codes from yellow = medium to dark green = very good).



7.1.3.2 Taxonomic resources

Checklists

Checklists exist for many European countries, but are often not necessary as the information is usually included in field guides, Red Lists or similar resources. A checklist by Wiemers et al. (2018) covers all European butterfly species.

Field guides

Many excellent field guides are available for European butterflies and several cover the whole of Europe (e.g. Lewington & Whalley 2000, Lafranchis 2004, Tolman 2009, Tshikolovets 2011, Haahtela et al. 2019). For many countries, field guides are also available in their national languages, e.g. Belgium and the Netherlands (Wynhoff et al. 2014), Cyprus (Makris 2003), Czech Republic (e.g. Bélin 1999), Denmark (Hermansen 2010), Estonia (Õunap & Tartes 2014), Finland (Haahtela et al. 2006), France (e.g. Tolman & Lewington 2015, Lafranchis 2016), Germany (Settele et al. 2015), Hungary (Gergely et al. 2017, Tóth 2019), Ireland (e.g. Harding 2008, DNFC 2010), Lithuania (Ivinskis & Augustauskas 2004), Poland (Sielezniew & Dziekańska 2010), Portugal (Maravalhas 2003), Spain (Objectiu Natura 2012), Sweden (e.g. Eliasson et al. 2005) and the UK (e.g. Thomas & Lewington 2014, Newland et al. 2015). An incomplete guide exists for Slovenia (Polak 2009). Some Italian field guides cover smaller regions, such as the Alps (Ferretti 2012). Austrian butterfly species are covered by a field guide for Bavaria, which, however, contains some errors (Stettmer et al. 2007). For Malta, a field guide is in preparation (Cassar in prep.).

Handbooks and identification keys

Given the high quality of available field guides, identification keys are largely irrelevant for butterflies. Larger handbooks exist for many countries, such as Bulgaria (Abadjev 1993a,b, 1995), Finland (Marttila et al. 2000), Greece (Pamperis 2009), Hungary (Abafi-Aigner 1907, Gozmány 1968, Varga 1984, Bálint 1996, Kádár et al. 2010), Ireland (Harding 2008), Poland (Sielezniew & Dziekańska 2010, Buszko & Masłowski 2015), Romania (Rákosy 2013), Slovakia (Macek 2015), Spain (García-Barros et al. 2013) and Sweden (Eliasson et al. 2005). A comprehensive handbook for Baden-Württemberg (Germany) covers nearly all German species (Ebert & Rennwald 1993a,b).

Online ID tools

Several online identification platforms are available for European countries. In the Netherlands and Belgium, the mobile device App 'Obsidentify'[63] provides automatic identification of many insects, including butterflies. Several apps for butterfly identification exist, including the Czech Republic[64], Germany[65] and Greece[66]. Online identification tools are available for Wallonia in Belgium[67], Bulgaria[68], Czech Republic[69], Cyprus[70], Denmark[71], Germany[72], Hungary[73], Ireland[74], Latvia[75], Luxembourg[76], Netherlands[77], Slovenia[78], Sweden[79] and the UK[80].

Atlases

For many European countries, distribution atlases for butterflies are available. These include Austria (Reichl 1992), Belgium (Flanders: Maes et al. 2013, Wallonia: Fichefet et al. 2008), Bulgaria (Abadjiev 2001), Croatia (Jakšić 1988), Cyprus (Markis 2003), the Czech Republic (Beneš et al. 2002), Estonia (Tiitsaar et al. 2019), Finland (Saarinen & Jantunen 2013), Greece (Pamperis 2009), Ireland (Nash et al. 2010), Italy (Balletto et al. 2007), Lithuania (Ivinskis & Augustauskas 2004), Netherlands (Bos et al. 2006), Poland (Buszko 1997), Romania (Rákosy et al. 2003), Slovenia (Verovnik et al. 2012), Sweden (e.g. Eliasson et al. 2005, Bengtsson et al. 2016), the UK (e.g. Fox et al. 2015), and the Iberian Peninsula (García-Barros et al. 2004). An atlas for Germany is currently in press (Reinhardt et al. in press). In France and Hungary, several regional atlases exist, but no national one. In Hungary, a national atlas for protected species is available (Bálint et al. 2006). In Luxembourg, an atlas is in preparation.

Online atlases and recording schemes

A European online atlas project (LepiDiv)[81] provides distribution maps for all European butterfly species. Online recording schemes are available in Belgium[82], Denmark[83], Estonia[84], Finland[85], France[86], Ireland[87], Latvia[88], Luxembourg[89], Netherlands[90], Poland[91], Sweden[92] and the UK[93]. In Spain, the Catalan ornithological recording scheme[94] is used for butterfly recording, and some national recording schemes exist as well[95]. For Greece and Slovenia, recording schemes are currently under development. In other coun-

63 https://www.natuurpunt.be/nieuws/natuurherkenner-je-broekzak-met-de-app-obsidentify-20200326
64 https://play.google.com/store/apps/details?id=cz.hotarekv.atlas&hl=cs;%20
65 https://play.google.com/store/apps/details?id=org.apache.cordova.schmetterling&hl=de
66 http://www.pamperis.gr/btf_site/
67 http://biodiversite.wallonie.be/fr/determinations.html?IDC=798
68 http://www. butterfliesofbulgaria.com/main%20menu.html
69 http://www.lepidoptera.cz/klic/
70 http://www.cyprusbutterflies.co.uk/
71 http://lepidoptera.dk/guide/index.php; https://www.fugleognatur.dk/felthaandbogen.asp?mode=indhold3&ordenID=1; www.danske-natur.dk
72 https://www.ufz.de/tagfalter-monitoring/index.php?de=41776
73 http://jasius.hu/lepidopterology/; www.macrolepidoptera.hu
74 http://www.biodiversity ireland.ierecord-biodiversity/butterfly-monitoring-scheme/about/how-to-identify-butterflies/
75 https://dabasdati.lv/site/img/pub/1/2/46/1336567356.pdf; https://dabasdati.lv/site/img/pub/1/2/147/1358159007.pdf; https://dabasdati.lv/site/img/pub/1/2/145/1357548334.pdf
76 http://naturemwelt.lu/biodiversite/download/Papillon_DE.pdf
77 https://www.vlinderstichting.nl/vlinders/vlinders-herkennen/
78 http://dbiodbs.units.it/carso/chiavi_pub21?sc=654
79 http://www.lepidoptera.se; http://www.vilkenart.se/https://artfakta.se/artbestamning/taxon/papilionoidea-2002976
80 https://butterfly-conservation.org/butterflies/identify-a-butterfly
81 https://www.ufz.de/european-butterflies/index.php?en=42605
82 http://biodiversite.wallonie.be/fr/papillons.html?IDC=797; waarnemingen.be
83 https://www.sommerfugleatlas.dk/; https://www.fugleognatur.dk/
84 https://lva.keskkonnainfo.ee/; https://elurikkus.ee/
85 Species.fi
86 http://www.vigienature.fr/fr/propage; http://www.vigienature.fr/fr/suivi-temporel-des-rhopaloceres-de-france-sterf; http://www.vigienature.fr/fr/operation-papillons
87 http://www.biodiversityireland.ie/record-biodiversity/butterflyatlas/
88 Dabasdati.lv; https://laji.fi/theme/nafi/instructions
89 mdata.mnhn.lu
90 https://waarneming.nl/; www.telmee.nl; https://www.vlinderstichting.nl/vlinders /overzicht-vlinders/details-vlinder/spiegeldikkopje
91 http://lepidoptera.ksib.pl/index.php?id=mp&l=en
92 www.dagfjarilar.lu.se
93 https://butterfly-conservation.org /our-work/recording-and-monitoring/irecord-butterflies
94 https://www.ornitho.cat
95 https://www.biodiversidadvirtual.org/insectarium/

tries, online atlases are available, such as the Czech Republic[96], France[97], Germany[98], Greece[99], Italy[100], Latvia[101] and UK[102]. The Lithuanian database (LepiBase) is hosted privately.

Monitoring

Contrary to other pollinator taxa, a well-established European butterfly monitoring scheme[103] exists in many European countries (section 1.2.2), which is constantly expanding. A monitoring programme has just been established in Austria and Cyprus, which will start in 2020. In Belgium (Flanders) it has been in place since 1991 with ~270 sites, in Wallonia with ~150 sites, in the Czech Republic with ~70 sites, in Estonia since 2004 with 10 sites, in Finland since 1999 with~110 sites, in France since 2001 with ~400 sites, in Germany since 2005 with ~1.000 sites, in Hungary since 2016 with 30 sites, in Ireland since 2007 with ~300 sites, in Italy since 2018 with ~45 sites, in Latvia with 35 sites, in Lithuania with 16 sites, in Luxembourg since 2010 with ~150 sites, in the Netherlands since 1990 with ~2,000 sites, in Portugal since 2019 with 5 sites, in Romania with 18 sites, in Slovenia since 2017 with ~40 sites, in Catalonia (Spain) since 1994 with ~160 sites, in the Basque Country (Spain) since 2010 with ~70 sites, in Spain (other parts) since 2014 with ~100 sites, in Sweden since 2010 with ~500 sites and in the UK since 1976 with ~2,000 sites. In Greece, monitoring focuses on the species listed in the EU Habitats Directive. Two national monitoring schemes exist in Latvia. Monitoring schemes are also under development in Croatia and Poland.

National Red Lists

A European Red List has been published in 2011 (van Swaay et al. 2011) and a reassessment is currently being instigated. A publication by Maes et al. (2019) gives a good overview of the existing national Red Lists for butterflies. National Red Lists exist in most European countries, except for Cyprus, Malta, and Portugal. For the latter two countries, Red List projects have recently been started. For some countries, such as Bulgaria and Slovakia, the Red Lists are very incomplete and cover only a few species.

Internet fora or discussion groups

Several experts have reported that internet fora exist in their countries: Austria[104], Belgium[105], Cyprus[106], Czech Republic[107], Denmark[108], Estonia[109], Finland[110], France[111], Germany[112], Greece[113], Hungary[114], Italy[115], Lithuania[116], Luxembourg[117], Malta[118], Netherlands[119], Poland[120], Portugal[121], Slovenia[122], Spain[123], Sweden[124], and UK[125].

96 https://portal.nature.cz/publik_syst/nd_nalez-public.php?idTaxon=31620
97 https://inpn.mnhn.fr/accueil/index
98 https://www.ufz.de/tagfalter-atlas/
99 http://www.pamperis.gr/btf_site/
100 http://www.faunaitalia.it/ckmap/
101 ej.uz/tv5x5
102 www.nbnatlas.org
103 https://butterfly-monitoring.net/able
104 www.schmetterlingsapp.at
105 https://www.facebook.com/Vlinderwerkgroep-van-Natuurpunt-356745054440335/; Forum Lycaena (Lycaena@yahoogroups.com)
106 http://www.cyprusbutterflies.co.uk/; Cyprus Butterfly Study Group on Facebook
107 Facebook group Biodiverzita nad zlato
108 www.lepidoptera.dk; www.danske-natur.dk; www.fugleognatur.dk; www.https://aarhus-entomologklub.dk; http://www.nlk.dkx.dk/
109 Two Facebook groups are devoted to Estonian butterflies and moths
110 Facebook group https://www.facebook.com/groups/suomenotokat/
111 https://insecte.org/
112 http://www.lepiforum.de/
113 http://portal.cybertaxonomy.org/flora-greece/intro
114 http://lepketerkep.termeszet.org/
115 http://www.iucn.it/scheda.php?id=468643719
116 Facebook group of the Lithuanian Entomological Society / closed e-mail forum
117 pimpampel@googlegroups.com
118 http://www.maltawildplants.com/forum/viewforum.php?f=9
119 forum.waarneming.nl
120 https://www.entomo.pl/forum/
121 https://www.facebook.com/groups/LepidopteraPortugal/
122 Mailing list of the DPOMS (Society for Conservation and Study of Lepidoptera of Slovenia)
123 Facebook group Mariposas y Polillas; Facebook group BMS España recording scheme; https://www.biodiversidadvirtual.org/insectarium/
124 http://www.dagfjarilar.lu.se/forum; https://www.facebook.com/groups/369088230659/; https://www.facebook.com/groups/122247664456987/
125 https://www.facebook.com/groups/239297882845682/; https://www.facebook.com/groups/113572275415525; https://www.facebook.com/BeesMothsandButterfliesUK/


Cyclyrius webbianus, Axel Hochkirch

DNA-Barcoding

Knowledge on the availability of DNA barcodes among butterfly experts is quite limited. A German online database[126] lists 162 barcoded species (29 species not collected, 3 species collected, but not barcoded; accessed 18 Oct 2019). According to experts, ~50 species are barcoded in Bulgaria, ~125 in Croatia, ~10 in Cyprus, more than 200 in Italy and ~180 in Romania. Experts from some countries (Portugal, Spain, Sweden, and the UK) reported that all species are barcoded. The Italian butterfly fauna is 93%

126 https://www.bolgermany.de/

processed in the framework of the project 'Barcoding Italian Butterflies'[127]. A paper by Dincă et al. (2015) lists 299 barcoded species for Europe. It is likely that this number has meanwhile substantially increased, but many scientists submit barcodes only to a database after they have published their results.

Availability of experts

There is a large number of experts available in most European countries. Additionally, numerous experienced amateurs exist in many countries. Only a few country experts reported five or less experts (e.g. Bulgaria, Croatia and Cyprus). Fewer than ten experts have been reported for Ireland, Italy, Latvia, Lithuania, Malta, Poland, Slovakia and Slovenia. Between 10 and 30 experts have been mentioned for Austria, Estonia, Greece, Hungary, Luxembourg, Portugal, Romania and Spain. Up to 50 experts were listed for Belgium and France, 80 for the Czech Republic, ~100 for Denmark, between 100 and 200 in Finland, ~200 in Sweden, ~300 in Germany, ~1,000 in the Netherlands, and ~1,500 in the UK. Although the definition of an expert may differ among the assessors, some reports differentiated between professionals and experienced amateurs in their countries (Belgium ~500 amateurs, Czech Republic ~150, Latvia ~40, and Spain ~300).

Meetings and organisations

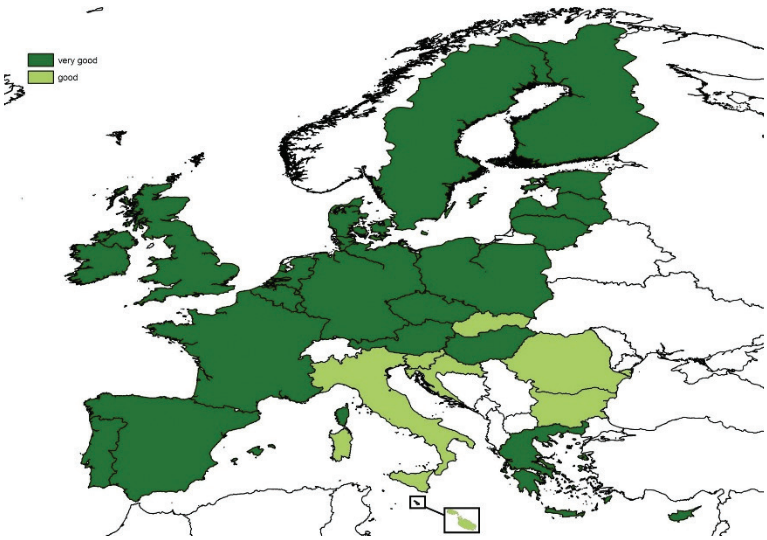
In many European countries, Lepidopterological societies exist, and/or yearly meetings are being held. In Belgium, the Flemish Butterfly Study Group organises a one-day symposium every two years. In Wallonia, the Lycaena Working Group[128] exists. In Cyprus, a Cyprus Butterfly Study Group was formed in 2012, which is also a 'Network partner' of Butterfly Conservation Europe. The Czech Society for Butterfly and Moth Conservation (SOM) meets twice a year together with the Slovakian colleagues[129]. In Denmark, the Lepidopterologisk Forening[130] exists in Copenhagen. The Estonian Lepidopterologists' Society holds its meetings twice per year. The Finnish Lepidopterological Society[131] organises meetings and publishes the journal Baptria four times per year and has about 1,000 members. In France, several regional meetings of Lepidopterists exist. The German Butterfly experts[132] meet yearly in the context of the monitoring scheme and there are several regional entomological societies and meetings. The Hungarian Lepidopterological Club (Szalkay József Magyar Lepkészeti Egyesület organises annual meetings, and the Hungarian Entomological Society (Magyar Rovartani Társaság) has regular monthly meetings. In Ireland, the NGO Butterfly Conservation Ireland[133] was established in 2008, and the National Biodiversity Data Centre[134] manages the Irish Butterfly Monitoring Scheme and runs the Butterfly Atlas 2021 project. Members of the Italian Barcoding team[135] meet once a year for a week to collect butterflies. The Associazione Italiana Lepidotterologia (ALI)[136] conducted a butterfly week in 2019. In the Netherlands, an annual butterfly day with ~650 participants is held. In Portugal, a first meeting for the monitoring (EBMS Portugal) is planned for 2020. In Romania, the Lepidopterological Society of Romania has a yearly meeting with about 20 participants. The Society for Conservation and Study of Lepidoptera of Slovenia (DPOMS) was established in 1999 and has ~45 members. In Spain, two organisations are devoted exclusively to Lepidoptera: SHILAP which publishes the journal Shilap Revista de Lepidopterología and the Societat Catalana de Lepidopterología which also publishes a Bulletin and holds regular meetings. Several meetings are held in Sweden: the annual floristic and faunistic conference[137] in Uppsala, the annual Swedish Entomological Society meeting, meetings of the Butterfly Society of Pite Lappmark[138], annual meetings of the expert committee for Lepidoptera for the Swedish Red List in Artdatabanken (the Swedish Species Information Centre) and meetings of local branches of the Swedish Butterfly Monitoring Scheme. Annual meetings are also held in the UK (plus national meetings, e.g. in Scotland). Several experts also mentioned general entomological societies or meetings. In the Czech Republic, the Česká společnost entomologická[139] organises meetings twice a year. In Latvia, Lepidopterists are organised in the Entomological Society of Latvia, and in Lithuania in the Lithuanian Entomological Society. An entomological workgroup of the Societé des Naturalistes luxembourgeois (SNL) regularly meets in Luxembourg. In Malta, there is a local entomological society, which publishes a Bulletin. The Polish Entomological Society has a Lepidopterological section.

127 http://www.barcodingitalianbutterflies.eu/
128 http://biodiversite.wallonie.be/fr/groupe-de-travail.html?IDC=3339
129 http://www.lepidoptera-som.cz/en_home.html
130 http://www.lepidoptera.dk/
131 http://www.perhostutkijainseura.fi/
132 https://www.ufz.de/tagfalter-monitoring/
133 https://butterflyconservation.ie/wp/
134 http://www.biodiversityireland.ie/record-biodiversity/butterfly-monitoring-scheme/
135 https://barcoding .wixsite.com/italianbutterflies/eventi
136 http://www.lepidoptera.life/
137 https://www.artdatabanken.se/ omartdatabanken/flora-och-faunavardskonferensen/
138 https://ffpl.weebly.com/
139 https://www.entospol.cz/

7.1.3.3 Overall quality of taxonomic resources in each country

The following map (Figure 7.4) provides an overview on the quality of existing taxonomic resources in each EU 27 country and the UK. The map was built based upon the question "which resources would be available for an amateur to start working on the respective pollinator group" in each country. The colour codes range from red (very poor taxonomic resources available, usually a checklist, but no keys, field guides etc.) to very good (high quality field guides or online resources available). Good identification literature exists for all countries, but not always in the national language.

Figure 7.4. Availability of taxonomic resources to identify butterflies in the Member States of the European Union and the UK (dark green = numerous or very good identification tools available, green: good resources, but no recent field guides in the national language).



7.1.4 Hoverflies (Syrphidae)

Around 979 hoverfly species have been reported for Europe (Speight 2020), and these are among the most abundant and conspicuous Dipteran species. Their ecology is largely determined by the requirements of the larvae, which vary substantially in biology and feeding mode, including mycophages, phytophages, saprophages and entomophages. Adults mainly feed on pollen and nectar (Thompson & Rotheray 1998).

7.1.4.1 Expert opinion on the taxonomic knowledge in each country

The following experts provided information on hoverflies in each country:

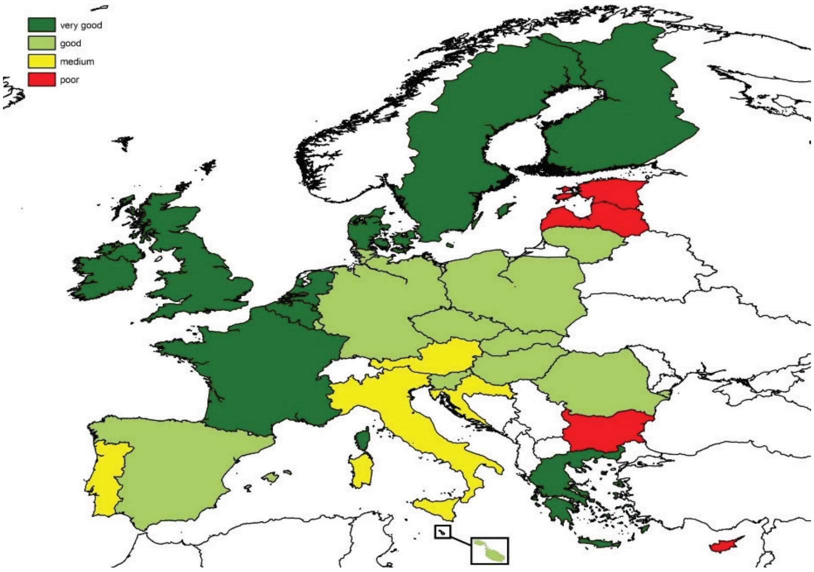
Austria: Helge Heimburg
Belgium: Frank Van de Meutter
Bulgaria: Ante Vujić
Croatia: Ante Vujić
Cyprus: André van Eck
Czech Republic: Libor Mazánek
Denmark: Hans Henrik Bruun; Rune Bygebjerg
Estonia: Olavi Kurina
Finland: Gunilla Ståhls-Mäkelä
France: Cédric Vanappelghem
Germany: Axel Ssymank
Greece: Laura Likov; Ante Vujić
Hungary: Sándor Tóth
Ireland: Martin Speight; Úna FitzPatrick
Italy: Daniele Sommaggio
Latvia: Dagmāra Čakstiņa
Lithuania: Erikas Lutovinovas

Luxembourg: Alexander Weigand
Malta: Martin Ebejer; Paul Gatt
Netherlands: Jeroen van Steenis; Wouter van Steenis; John Smit
Poland: Łukasz Mielczarek
Portugal: André van Eck; Ana Rita Goncalves
Romania: Amalia Balasoiu
Slovakia: Libor Mazanek
Slovenia: Marteen De Groot
Spain: Antonio R. Ricarte Saber; M. Ángeles Marcos-García
Sweden: Rune Bygebjerg
UK: Francis Gilbert

Full responses country by country are provided in Appendix 7.3.

The map below (Figure 7.5) illustrates the taxonomic knowledge in the EU27 countries and the UK according to expert opinions (see question 1 in section 7.1.1). Generally, taxonomic knowledge is rated higher in the northwest of the continent than in the east and south.

Figure 7.5. Expert opinion on the taxonomic knowledge on hoverflies in the Member States of the European Union and the UK (colour codes from red = poor to dark green = very good).



7.1.4.2 Taxonomic resources

Checklists

Checklists are an important tool for insect identification as they provide information on which species are to be expected in a given country. Checklists exist for nearly all countries, except for Croatia. In some countries (e.g. Bulgaria) the checklist is very old (Bankowska 1967), while in most others the checklists were published during the last 10 to 20 years. For a few countries, new checklists are currently in preparation (e.g. Austria, Cyprus, Greece and Latvia).

Field guides

Field guides are the most important resource for amateurs to start working on insect groups. Good field guides mainly exist for the northwest of Europe. A field guide for northwestern Europe by van Veen (2010) covers Ireland, the UK, the Netherlands, Belgium, Luxembourg, Denmark, Sweden, Finland and large parts of the Baltic states , as well as parts of Germany and France. An excellent new field guide is available for Belgium and the Netherlands (Bot & Van de Meutter 2019). For Sweden, two volumes of a field guide by Bartsch et al. (2009a, b) are available, which are also used in neighbouring countries. Several field guides are available in the UK (Stubbs & Falk 2002, Ball & Morris 2015). Older (outdated) field guides exist for Romania (Brâdescu 1991), Denmark (Torp 1994) and Germany (Kormann 2002), the latter of which is not comprehensive.

Handbooks and identification keys

Identification keys to many European Syrphidae are available via Syrph the Net (StN, e.g. Speight 2016, Speight & Sarthou 2017). These keys are useful in many European countries and have been named as the primary source for France. Some comprehensive high-quality field guides have also been mentioned under this category. For example, the book by Bot & Van de Meutter (2019) for Belgium and the Netherlands, Stubbs & Falk (2002) for the UK, or van Veen (2010) for northwestern Europe. The two-volume book by Bartsch et al. (2009a, b) covers all species from Sweden, Norway, Finland and Denmark. A handbook exists also for Finland and adjacent countries (Haarto & Kerppola 2007). In Germany, a monograph by Bastian (1994) and a key by Bothe (1996) exist, both of which are not comprehensive. Therefore, keys from neighbouring countries (van Veen 2010, Bot & Van de Meutter 2019) are also used. For Greece, a key to the genera is available in the Greek atlas (Vujić et al. 2020) as well as for Italy (Bertollo & Sommaggio 2012).

Online ID tools

An online platform in France[140] contains 3,662 photos of 488 species. This platform is also used in neighbouring countries. In Germany, an online key[141] for Syrphidae is available. A couple of online resources are available for Ireland and the UK[142]. In Sweden, online ID help is provided by the online recording scheme[143].

Atlases

Distribution data is very important to facilitate the identification of species and exclude species that are unlikely to occur in a given region. For Belgium, atlas data is included in Bot & Van de Meutter (2019). Atlases also exist for Ireland (Speight 2008), Netherlands (Reemer et al. 2009), Sweden (Bartsch et al. 2009a, b), Hungary (Tóth 2011), the UK (Ball et al. 2011) and Greece (Vujić et al. 2020). For Lithuania, an atlas is in preparation (Lutovinovas in prep.). Older atlases are available in Denmark (Torp 1984, 1994) and for the Syrphinae subfamily in Italy (Sommaggio 2005).

Online atlases or recording schemes

Online recording schemes are available in Belgium[144], Denmark[145], Estonia[146], Finland[147], Ireland[148], Latvia[149], Luxembourg[150], Netherlands[151], Slovenia[152] and UK[153]. For Italy, an online atlas exists for the Ferrara province[154].

National Red Lists

Red Lists provide valuable information on the conservation status of species. They help to evaluate the importance of a species record and are crucial for informing conservation planning and management. National Red Lists for hoverflies exist in the Czech Republic (Mazánek & Barták 2005), Denmark (Bygebjerg 2004, which is currently being updated), Estonia[155], Finland (Haarto et al. 2019), Germany (Ssymank et al. 2011), Sweden (SLU Artdatabanken 2020) and the UK (Ball & Morris 2014). A proposed Red List also exists for Italy (Burgio et al. 2015). Only four species have been assessed for the Spanish Red List (Verdú et al. 2011). A Red List is currently also being established for Portugal. Furthermore, a European Red List project is currently funded by the European Commission and expected to be published in 2021.

140 http://cyrille.dussaix.pagesperso-orange.fr/L.html
141 https://offene-naturfuehrer.de/web/Schwebfliegen,_Syrphidae_ (Diptera)
142 http://www.biodiver-sityireland.ie/wordpress/wp-content/uploads/Beginners-guide-to-Irish-hoverflies-July-2015.pdf; https://pollinators.ie/record-pollinators/id-guides/
143 https://www.artportalen.se/
144 waarnemingen.be
145 https://www. svirreflueatlas.dk/; https://www.fugleognatur.dk/
146 https://elurikkus.ee/en
147 Species.fi
148 https://maps.biodiversityireland.ie/Dataset/159
149 www.dabasdati.lv
150 mdata.mnhn.lu
151 waarneming.nl
152 https://www.inaturalist. org/projects/hoverflies-of-slovenia
153 www.nbnatlas.org
154 https://storianaturale.comune.fe.it/564/atlante-on-line-dei-ditteri-sirfidi-del-ferrarese
155 https://infoleht.keskkonnainfo.ee/default.aspx?id=-598760291&state=3

Melanogaster nuda, Tamara Tot

Internet fora or discussion groups

Internet fora are useful to stimulate discussion among experts and amateurs and help to increase capacity in taxonomic knowledge. Several experts have reported that internet-fora exist in their countries: Austria[156], Belgium[157], Denmark[158], Finland[159], France[160], Ireland[161], Lithuania[162], the Netherlands[163], Portugal[164], Spain[165], Sweden[166], and the UK[167].

DNA-Barcoding

Knowledge on the coverage of hoverfly species by barcoding projects is limited among taxonomic experts. For Germany, an online database[168] is available that provides information about the current coverage (306 species barcoded, 83 not collected, 86 collected but not barcoded, yet; accessed 16 Oct 2019). Similar databases are lacking for the complete European continent or the EU27. For the Netherlands and Belgium, more than 220 barcoded species have been mentioned by the experts, but it is likely that there is a strong overlap with the German species. For Spain, 277 species (out of 421) are covered (15 Oct 2019), for Finland 256 barcoded species have been reported (but there is a current campaign to increase the number). The BOLD database[169] lists the following species numbers collected from each country: Austria, 5 species; Belgium, 5 species; Bulgaria, 3 species; Croatia, 5 species; Cyprus, 4 species; Czech Republic, 0 species; Denmark, 6 species; Estonia, 1 species; Finland, 66 species; France, 16 species; Germany, 119 species; Greece, 91 species; Hungary, 1 species; Ireland, 6 species; Italy, 38 species; Latvia, 0 species; Lithuania, 0 species; Luxembourg, 4 species; Malta, 1 species; Netherlands, 35 species; Poland, 2 species; Portugal, 2 species; Romania, 0 species; Slovakia, 0 species; Slovenia, 2 species; Spain, 54 species; Sweden, 47 species; and UK, 49 species. It also appears that many species have been sequenced several times by different national projects, while numerous species (particularly from the Mediterranean) are completely missing. Large barcoding projects, including many European species, are currently being conducted in the Universities of Novi Sad (Serbia) and Helsinki (Finland).

156 https://austria-forum.org/af/Natur/Fauna/Insekten/Fliegen/10_Syrphidae_-_Schwebfliegen
157 Waarnemingen.be / Whatsapp group
158 Naturbasen.dk; https://www.fugleognatur.dk/
159 species.fi; https://foorumi.laji.fi/; https://www.facebook.com/groups/suomenotokat/
160 https://www.insecte.org/forum/viewforum.php?f=11; https://fr.groups.yahoo.com/neo/groups/dipterasyrphidae2/conversations/messages / Diptera.info
161 https://www.facebook.com/groups/insectsinvertebratesire/
162 https://www.macrogamta.lt/lt
163 http://www.tuin-thijs.com/zweefvliegen-engels.htm; https://www.syrphidaeintrees.com/
164 Facebook group on Portuguese Diptera
165 https://www.biodiversidadvirtual.org/insectarium/
166 https://www.artportalen.se/
167 www.hoverfly.org.uk; https://www.facebook.com/groups/609272232450940; https://www.dipterists.org.uk/forum/1
168 https://www.bolgermany.de/
169 boldsystems.org

Availability of experts

The number of Syrphidae experts is very limited in most countries. In most countries, the number of hoverfly experts is below five. In some countries, there are no hoverfly experts at all (e.g. Croatia) or no residents deal with them (e.g. Malta, Greece). In many other countries, only one or two hoverfly experts are available (e.g. Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Romania and Slovakia). Up to five experts are available in Austria, Belgium, Finland, Italy, Luxembourg, Portugal and Sweden. A few country experts mention up to ten hoverfly experts (Denmark, France, Slovenia) and only in five countries is the number of experts more than 10 (Germany, Ireland, the Netherlands, Poland and the UK).

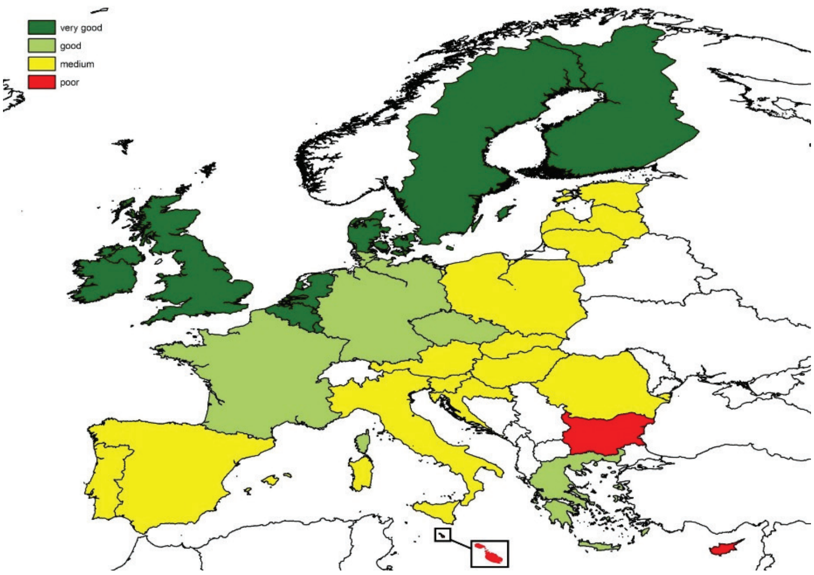
Meetings and organisations

A world hoverfly symposium is organised biannually. The last meeting took place in September 2019 in Greece. In Belgium, an annual informal midwinter meeting with (mostly Flemish) amateurs and some Dutch experts is held to discuss identifications, taxonomical issues etc. In the Czech Republic, there is an irregular meeting of Dipterologists[170]. French Syrphidae specialists[171] meet every three years. In the UK, regular meetings of the Dipterists Forum[172] are held and a Hoverfly recording scheme[173] is running. Regular meetings are also held in Poland. In Germany there is a working group on Diptera (AK Diptera[174]), which meets yearly. Furthermore, there are introductory courses on the biology and identification of hoverflies run by the NUA academy in North Rhine-Westphalia[175]. Similarly, the National Biodiversity Data Centre in Ireland runs identification workshops. In Italy, the Ferrara Museum of Natural History organises a course for Syrphidae identification. A section Diptera also exists in the Netherlands Entomological Society. Other Syrphidae experts attend broader entomological conferences, such as the Entomological Society of Latvia, the Lithuanian Entomological Society or the Iberian Congress of Entomology. In Finland, several entomological societies exist in cities (Helsinki, Turku, Tampere and Oulu).

7.1.4.3 Overall quality of taxonomic resources in each country

The following map (Figure 7.6) provides an overview on the quality of existing taxonomic resources in each country. The map was built based upon the question "which resources would be available for an amateur to start working on the respective pollinator group?" in each country. The colour codes range from red, which indicates very poor taxonomic resources available (usually a checklist, but no keys, field guides etc) to green, which indicates very good (high quality field guides or online resources available).

Figure 7.6. Availability of taxonomic resources to identify hoverflies in the member states of the European Union and the UK (from red = no or very limited resources available to dark green = numerous or very good identification tools available).



170 http://www.fpv. umb.sk/katedry/katedra-biologie-a-ekologie/veda-a-vyskum/konferencie/10-stredoeuropska-dipterologicka-konferencia/
171 https://app.box.com/s/fqcxc8e5eiuaukuqh2r8euulwgvky4bd
172 http://www.dipteristsforum.org.uk/
173 http://www.hoverfly.org.uk/
174 http://www.ak-diptera.de/
175 https://www.nua.nrw.de/veranstaltungen/hinweise/artikel/1943-einfuehrung-in-die-oekologie-und-bestimmung-heimischer-schwebfliegen/detail/

7.2 Proposal to bridge the taxonomic gap to facilitate pollinator monitoring in Europe

Based upon the assessment of the current taxonomic expertise and resources on key pollinator taxa in Europe (section 7.1), this section aims to provide guidance on how the taxonomic gaps of knowledge can be closed to achieve the required levels of species identification capability for a European pollinator monitoring scheme.

Proper taxonomic knowledge is crucial to avoid errors in data acquisition. Taxonomic knowledge transfer includes thorough reviews of the species existing in each country (checklists, digital availability of museum data), proper identification literature (field guides, keys, online tools, and mobile device applications), information on distribution (atlases) and rarity (Red Lists) and taxonomic training (courses). Furthermore, considering the rapid developments in DNA barcoding techniques, comprehensive barcodes of the European fauna will be increasingly important for rapid analyses of large samples.

For each taxonomic resource a short background is given along with some basic requirements. Following this is an assessment of the current status of the resource and action(s) needed to enhance it to a level sufficient to support the EU-PoMS. Based upon a prioritisation exercise during an expert group meeting, the approaches below (sections 7.2.1 to 7.2.10) have been ordered from highest to lowest priority, though the experts recognise that all these submitted capacity building measures require action and many of them are related. Finally, we propose a concrete target and suggested delivery date (contingent upon resourcing available) for each taxonomic resource option, along with an estimated cost. This cost estimates were derived from experience with similar projects and by asking experts in the respective field.

7.2.1 Capacity building and training

Background

In order to set up a monitoring scheme, taxonomic expertise needs to be available in each country. Identification courses are useful to train amateurs in identifying pollinators as well as improving expert knowledge. For a voluntary monitoring scheme, good training in identification as well as good mentoring is crucial. For a professional pillar, good taxonomic training is necessary to be able to process the large number of samples.

Details

Basic training courses should be provided in all countries. These should provide information on important diagnostic traits, but also on the ecology and biology of species as well as field methods (like the training schools of the COST SUPER-B project[176]). Basic courses should be complemented by more advanced courses focusing on species-rich or difficult taxa. The latter could first be provided at a European scale, but later should be conducted regionally (e.g. Iberian, Atlantic Islands). A proper strategy is needed to reach the necessary capacity in each country. Courses in Universities should be integrated into the curricula to train a new generation of taxonomic experts. The development of a professional recording scheme will help to create incentives for this. Central facilities, responsible for monitoring in the respective country, could offer identification courses, coordinate volunteers and organise annual meetings (which is already done for butterflies in many countries). Collaboration between international taxonomists and local experts should be encouraged to develop new courses where they are lacking, or supplement existing ones. Well-maintained comprehensive national reference collections are an important resource for training taxonomic experts, while less comprehensive local collections are required for training beginners.

Status

Butterflies: In most countries, taxonomic knowledge of butterflies is sufficient to start monitoring. Sampling methods are well-established. Field and lab courses for species identification exist in many countries and will help to further increase capacity in countries with few amateurs. Hoverflies and wild bees: Identification courses exist in some countries. The COST SUPER-B project has compiled courses on wild bees focusing on ecology, while others have focused on taxonomy (like BienABest[177] in Germany, or the 5-day practical course "Introduction to the taxonomy of wild bees" by CREA in Italy).

Action needed

- Comprehensive national reference collections need to be established in each country for training experts and scholars (ideally in the national monitoring centre)

176 http://superb-project.eu/
177 https://www.bienabest.de/bienabest

- Various smaller collections are needed for training courses
- Identification courses need to be developed in countries where no courses currently exist
- Existing courses need to be supported and refined.
- An evaluation of the effectiveness of training is useful for optimisation.

Proposed targets:

i. *Basic training courses* available for all three taxa in each target region by 2022. Deliverables: for hoverflies and bees: 2 weeks training, covering taxonomy, but also field methods, ecology, and biology; for butterflies focusing on establishing the voluntary monitoring scheme. Courses by two trainers (one local and one foreign expert) with 5-10 participants. One course for each of the following target regions (considering biogeography and language barriers): Atlantic Islands, Iberian Peninsula, France & Luxembourg, Italy & Malta, Greece, Cyprus, Bulgaria, Romania, Hungary, Slovenia & Croatia, Austria, Czech Republic & Slovakia, Poland, Germany, Belgium & Netherlands, Denmark, Sweden, Finland, Baltic States, Cyprus, and Ireland.

ii. *Advanced training courses* (covering taxonomy of difficult taxa) available in each target region by 2023. Deliverables: 2 weeks training, covering taxonomy of difficult genera. Courses by two trainers (one local and one foreign expert), 5-10 participants.

iii. *National reference collections*, plus a pan-European one are available by 2024. Deliverables: One comprehensive reference collection for each country (including at least one male and one female of each species occurring in the respective country as far as possible), stored in a properly maintained collection (e.g. museum) and continuously maintained.

iv. *Training collections* are available by 2022 for use in training courses (but need to be continuously maintained). Deliverables: For each basic training course, collections including a broad variety of taxa are required. Each species needs to be present in a sufficient number (at least one specimen for each participant), i.e. 10 replicates of each training collections are required. The collections need to be constantly maintained and broken specimens replaced.

Estimated costs:

v. *Basic training courses* (for all three taxa):
  — equipment acquisition (microscopes, training collection, books): €40,000
  — implementation (2 trainers for 2 weeks, 5-10 participants, consumables, travel costs): €30,000 per course (i.e. per country per year)

vi. *Advanced training courses* (for hoverflies and wild bees):
  — implementation (2 trainers for 2 weeks, 5-10 participants, consumables, travel costs): €30,000 per course (i.e. per country per year)

vii. *National reference collections*: €50,000 per Member State

7.2.2 European field guides and identification keys

Background

During recent decades, the quality of field guides and identification keys has increased substantially allowing more people to accurately identify insects to groups or species. In many countries, the use of primary literature is still necessary to identify pollinators (particularly hoverflies and wild bees). The publication of field guides is often based upon personal interests and many identification tools have been privately published or are difficult to access. For butterflies, European field guides have been translated into many European languages, but similar comprehensive literature is largely lacking for the other taxa. Promoting the publication of European high quality field guides and identification keys will help to create national field guides subsequently.

Ammobates muticus, Nicolas J. Vereecken

Details

The text of European field guides should be in English, but translations to other languages will help to promote capacity building in other European countries. The field guides should be comprehensive to ensure that future experts will be aware of species in neighbouring countries or adjacent regions. They should be written in collaboration by experienced taxonomists and include high quality photos (or drawings) of the diagnostic traits, distribution maps and information on the habitats and biology of each species. Dichotomous keys can be included as these are useful for experienced entomologists, but are often difficult to use for laypersons.

Status

A good European field guide is available for butterflies. For hoverflies, a field guide to northwestern Europe is available, for wild bees field guides are available for some northern European countries. Recently, the book 'Bees of Europe' has been published (with keys to the genera, but not to all species).

Action needed

- Fund networks of experienced European taxonomists to write field guides

Proposed targets:

i. (*A comprehensive European field guide and/or identification keys for hoverflies* available by 2025. Deliverables: Field Guide and/or identification keys covering all European hoverfly species, text in English, including high quality photos (and/or drawings) of the diagnostic traits, distribution maps and information on habitats and biology of each species.

ii. *A comprehensive European field guide and/or identification keys for wild bees* is available by 2025. Deliverables: Field Guide and/or identification keys covering all European wild bee species, text in English, including high quality photos (and/or drawings) of the diagnostic traits, distribution maps and information on habitats and biology of each species.

Estimated Costs:

iii. *European field guide and/or identification keys for hoverflies*: €300,000

iv. *European field guide and/or identification keys for wild bees*: €400,000

7.2.3 National field guides and identification keys

Background

While European field guides will provide a good basis of pan-European knowledge, field guides in national languages are often more suitable to engage laypersons. As they also include fewer species, they are more useful for beginners.

Details

The text should be written in the national language and the content comprehensive for the respective country. Species from adjacent regions should be included to make sure that these are not overlooked. For some regions, field guides for a region may be more useful than national ones (e.g. France, Luxembourg and Belgium). Similar to the European field guides, the national ones should include high quality photos and/or drawings of diagnostic traits as well as information on proper preparation of insects. Distribution maps and information on habitats and biology should also be included. If based upon a European field guide (section 7.2.2), it might be more feasible to produce excerpts in the national languages containing the species occurring in the respective country.

Status

For butterflies, national (or regional) field guides exist for most countries, but publication in national languages would be beneficial in some countries to facilitate citizen science (e.g. Bulgaria, Croatia, Italy, Latvia, Malta, Romania and Slovenia). For hoverflies and wild bees national field guides are largely lacking (except for some northern countries).

Action needed

- Fund experienced European taxonomists from the respective countries to write national field guides or translate excerpts of European guides

Proposed targets:

i. *National (or regional) field guides for butterflies* available in all European languages by 2023. Details: National field guides are needed in Bulgarian, Croatian, Italian, Latvian, Romanian, Slovakian, and Slovenian. Ideally, existing European guides (e.g. Tolman & Lewington) should be translated into these languages. Deliverables: Translation of Tolman & Lewington (2009, Collins Butterfly Guide)

ii. *National (or regional) field guides for wild bees and hoverflies* available by 2026, so that laypersons in each country can obtain the necessary identification literature. Deliverables: Translation of the European field guides (see section 7.2.2), but covering only the species occurring in the respective country (and some adjacent ones).

Estimated costs:

1. *National field guides for butterflies*: €25,000 per language (x 7 languages)
2. *National field guides for wild bees*: €40,000 per language and *National field guides for hoverflies*: €30,000 per language

7.2.4 DNA barcoding

Background

DNA barcoding and metabarcoding (i.e. barcoding of mixed samples) approaches are being increasingly used to analyse large samples and may also help to determine the identity of samples retrospectively. Currently, DNA barcoding is based upon a single mitochondrial gene fragment (COI), but recent technological advances also allow sequencing of larger parts of the genome (or even whole genomes). Barcodes are stored in the Barcode of Life Database (BOLD[178]) as well as some other databases, but some scientists often wait to complete comprehensive barcoding projects before transmitting data to the database, which creates a substantial delay.

178 www.boldsystems.org

Gonepteryx rhamni, Axel Hochkirch

Details

To create a comprehensive European DNA barcode library, voucher specimens need to be stored for each barcode produced (to avoid errors in the database and retrospectively adjust identifications). Barcodes must be available for every European species of the three main taxa of the EU-PoMS, and for several specimens of each species as far as possible, ideally covering the complete European range to reflect genetic variation across the continent. A common online platform must be available to readily obtain information on the current coverage and barcodes for all European species (BOLD is a good national example). This could be based upon an existing platform rather than developing a new one.

Status

Several independent barcoding projects exist all over Europe, usually organised in the iBOL consortium (international barcode of life). Most projects are based in the northern part of Europe, and there is substantial overlap in species coverage, while many rare and Mediterranean species are missing.

Action needed

- Targeted collecting and sequencing of species not covered so far.
- Avoidance of large overlaps, by better coordination across European barcoding projects and encouraging experts from species-rich southern European countries to establish new and extensive barcoding projects.
- European funding is required to start a pan-European barcoding project for pollinators with collaboration from many countries

Proposed targets:

i. *A comprehensive pan-European gap analysis* for all three taxa, is needed by 2021 to prioritise species for inclusion. Deliverables: Comprehensive species lists for butterflies, wild bees and hoverflies, including information, which species is covered by how many specimens in each database and which species are lacking.

ii. *Comprehensive barcodes of all species* should be available on a single European online platform by 2026. Details: Missing species need to be collected (or museum material used) to close gaps in the database. Deliverables: COI barcode information for all European pollinator species in the BOLD database.

Estimated costs:

iii. *Gap analysis*: €2,000

iv. *Completing the Barcode of Life for European pollinators*: €1 million

7.2.5 European recording schemes

Background

Information on the distribution of species is important to assist in their identification, and also for their conservation. Modern technology allows distribution data to be submitted online including in the field using mobile devices. However, the data needs to be validated and constantly maintained and adapted to changing taxonomies. Integrating historic data from the literature, naturalists' diaries and museum material helps make use of scarce historical data. Ensuring the data is open access and integrating them into online identification tools and apps can help to motivate naturalists to submit their own data.

Details

Rather than developing new databases, it would be important to extend existing ones and move to integrate data from multiple databases into a single platform (e.g. GBIF[179]). A common European platform (see section 7.3.3) could be based upon an existing one (e.g.Observation.org[180]), with online submission possible via an internet platform or a mobile device App. The records still need to be validated by experts (e.g. by the national or European monitoring centres). It should also be possible to submit photos and other information that may help to identify species. Minimum required information should be the species name, coordinates and date and follow a recognised standard (e.g. Darwin Core) and metadata should include method, status, habitat etc. Data should be clearly licensed (ideally CC0 or CC-BY) and ultimately passed on to GBIF.

Status

Numerous recording schemes exist in Europe (e.g. Observation.org, iNaturalist[181], Waarneming.nl[182] iSpot[183]), but currently they are not connected and pan-European information is, therefore, difficult to access. Data are not readily available for the whole of Europe (not all submit to GBIF), and not all schemes have a good validation system (sometimes resulting in erroneous entries that may be forwarded to GBIF). Two examples of high quality schemes are Observation.org and iNaturalist.

179 https://www.gbif.org/
180 euro.observation.org
181 https://www.inaturalist.org/
182 https://waarneming.nl/
183 https://www.ispotnature.org/

Action needed

- Use good existing platforms as a basis for a pan-European scheme
- Integrate data from other platforms into one for Europe

Proposed targets:

i. *Status report on the existing recording schemes* in Europe by 2022. Deliverables: detailed overview of the existing recording schemes, assessment of the qualities of data entry, validation, data storage, compatibility, spread of the system.

ii. *A pan-European recording scheme*, integrating the most important existing platforms, exists by 2025. Details: Rather than creating a new system, one existing system should be promoted, all data should be transmitted to GBIF. The system should fit the INSPIRE standard. Deliverables: internet platform for submission of records (e.g. euro.observation.org); comprehensive species lists of all European pollinators; minimum requirements: species, date, recorder name, coordinates; App for data collection in the field (e.g. ObsMapp).

iii. *Long-term maintenance of the European recording scheme*. Deliverables: Coordination and support of volunteers and validators, maintenance of the database, two permanent full staff.

Estimated costs:

iv. *Status report*: €20,000

v. *Establishment of a European interface* (based upon existing systems): €20,000

vi. *Maintenance of the European recording scheme*: €60,000 per year

7.2.6 Annotated national checklists

Background

A thorough review of the species existing in each country is important for identification and creation of field guides. Checklists are available for many countries, but not all are up-to-date, or they fail to consider new taxonomic changes. Where new field guides or online tools are available, checklists are usually included within these documents. Taxonomic knowledge constantly changes, but taxonomic research is not currently well coordinated or strategic (and often performed by laypersons). Some pollinator taxa are in need of more detailed taxonomic work, including molecular studies, and undescribed species are likely to occur in the Mediterranean, and on the Macaronesian Islands.

Details

The text of checklists should be in English as well as the national language to be accessible for local naturalists as well as for non-English speakers. For each taxon, some basic information on its status (distribution, rarity) should be included as this is valuable to assess records. The checklists will provide the basis for national field guides and Red Lists (and could be included in these documents). More detailed integrative taxonomic work should be facilitated and coordinated to better understand biodiversity in Europe.

Status

Checklists exist for most taxa and most countries, but they are not always up-to-date, or they lack a thorough discussion of difficult taxa. Taxonomic revisions are often based upon the general taxonomic interest of the experts involved rather than on a proper gap analysis.

Action needed

- Create annotated checklists for European countries where they are currently lacking
- Establish a funding scheme to support integrative taxonomic research. A central European coordination would help to prioritise taxa for taxonomic studies

Proposed targets:

i. *Annotated checklists available for all countries and taxa* by 2023 (they may be included in field guides or other publications). Deliverables: published annotated checklist in English and the respective national language.

ii. *A funding mechanism and coordination is established for integrative taxonomic research* for European pollinator taxa by 2025. Details: Taxonomic research needs a secure European funding mechanism to facilitate the taxonomic exploration of European pollinators. Deliverables: Funding of 10 taxonomic projects per year to study the taxonomy of pollinators, using multiple methods (including molecular tools), each project funded for 3 years (with option to extend for another year).

Estimated costs:

iii. *Checklists*: €30,000 per checklist on average (ranging from €20,000 to €50,000, depending on species richness of the country). Funding of one half-time staff member for one year to compile a national checklist.

iv. Funding mechanism for integrative taxonomy: €600,000 per year. Budget of each project €60,000 per year.

7.2.7 Online identification tools

Background

Online identification tools are more flexible in integrating new information as it arises, and can become a live database for identification, which is continuously being improved. They can also provide a larger number of data, including links to growing atlas data or more photos.

Details

Online identification tools should be open access to ensure that they are freely available. They should be comprehensive for Europe with tools to switch to all (major) European languages and filter species by country. They can be based upon the European

Osmia andrenoides, Nicolas J. Vereecken field guides (i.e. internet access to the full book content), but can provide more photos etc. High quality photos or drawings of main diagnostic traits should be included as well as distribution maps and information on habitats and biology.

Status

Online identification tools exist in many countries for butterflies, but the quality is quite heterogeneous. For hoverflies and wild bees, online identification tools exist only in a few countries, sometimes providing just photos (which may be informative for experts, but not for laypersons). Some European projects (e.g. Syrph the Net, Atlas Hymenoptera) provide a basis (dichotomous keys, atlas data) for such tools. Online identification tools are also available for other taxa[184].

Action needed

- Fund taxonomic experts and IT specialists to develop a pan-European internet identification platform for pollinators, which is constantly maintained and updated (e.g. coordinated by a European monitoring centre).

Proposed target:

i. *An online identification platform* available by 2025, maintained and constantly improved. Deliverables: Online platform with capacity to store information on identification, distribution, ecology and biology of all European pollinator species, including photos, drawings, distribution maps and interactive keys.

Estimated costs:

ii. *Online identification platform*. Establishment of the platform: €60,000. Maintenance of the platform: 60,000 € per year. Details: constant updates of software and content based upon the latest scientific findings (requires one full staff member per year, but can be combined with maintenance of European monitoring database).

7.2.8 Mobile device applications

Background

Technological progress allows the development of new tools for mobile devices that are readily available in the field and may contain much more information than a traditional field guide. Such Apps may even include automatic image recognition software (e.g. ObsIdentify), which can be constantly improved using artificial intelligence.

Details

Apps can be based on the European field guide or online ID platform and should be comprehensive for Europe (with filter options for each country). They may even contain information for all three taxonomic groups. Distribution maps as well as information on habitats and biology should be included. Filtering species by traits and locality can facilitate identification. The most important traits for identification should be clearly illustrated. The text should be available in many (if not all) European languages. An image recognition software may be included (such as Obsidentify[185]), but similar species should be displayed.

Status

Currently, Apps are mainly available for butterflies and only for a few countries (e.g. App 'Butterflynder' by Bozano et al.). The quality is highly variable and not all apps provide information on the most important diagnostic traits.

Action needed

- Fund development of an App, either a new one or as an extension of existing ones

184 https://www.lucidcentral.org/key-search/; https://offene-naturfuehrer.de/web/Hauptseite
185 https://www.natuurpunt.be/nieuws/natuurherkenner-je-broekzak-met-de-app-obsidentify-20200326

Proposed target:

i. *App for European butterfly identification* available by 2024 (and continuously updated similar to the online identification platform, on which it may be based). Deliverables: App including all European butterfly species, distribution maps, photos from upper and underside, information on ecology and biology, identification tools (multi-criteria key, if possible automatic image recognition), available at least in English, French and Spanish (ideally in all official European languages)

ii. *Wild bee and hoverfly species* added in App by 2026.

Estimated costs:

iii. *App for European butterfly identification*: €80,000. Maintenance: €5,000 per year. Details: constant updates of software and content based upon the latest scientific findings (requires one full staff member per year, but can be combined with maintenance of European monitoring database).

iv. Addition of wild bees and hoverflies: €100,000 for hoverflies, €200,000 for wild bees.

7.2.9 Digitisation of collections

Background

Natural history collections maintain valuable information on species identities and historic distributions. They also provide the basis of taxonomic work by storing type material of all species. However, due to lack of capacity, many collections are not properly maintained, old material has not been re-identified and metadata on collection localities and dates are not readily available. Digitisation projects help to make such data accessible and implement them in existing databases. Photos of type material are important to inform taxonomic research, while metadata is important to infer population trends.

Details

Digitisation of museum collections is needed to make existing data more widely available for analyses. Most digitisation projects focus on the type material (which should indeed be a priority to inform taxonomy). Digitisation of metadata (particularly species, locality and date) is important to understand population trends of species and fully utilise historic data. Better integration of data from national or regional digitisation projects is required to make such data accessible on a single platform.

Status

Digitisation projects exist in several large European research museums (e.g. Natural History Museum London, Muséum national d'histoire naturelle Paris, Naturalis Biodiversity Center Leiden, Finnish Museum of National History). Some global projects exist as well (e.g. AntWeb[186]). In southern European countries these activities are poorly funded currently.

Action needed

- Establish a funding mechanism to comprehensively digitise pollinator species in European natural history collections.

186 http://antweb.org/

Proposed targets:

i. Photos of type material of all European butterfly, hoverfly and wild bee species available on a single internet platform, e.g. the comprehensive online identification key under (section 7.2.3) by 2025. Deliverables: photos of all types of European pollinator species (including several views, details of diagnostic traits and labels), access provided on an internet platform.

ii. Historic distribution data of the most important entomological collections is implemented in existing databases (particularly GBIF) by 2030. Deliverables: European funding mechanism for digitisation projects.

Estimated costs:

iii. *Digitisation of type material*: €100,000.

iv. *Digitisation of historic distribution data*: €300,000 per year (~€30,000 per project and year).

7.2.10 National Red Lists

Background

Red Lists provide important information to inform conservation planning and prioritise species for conservation. National Red Lists may vary substantially from European or global assessments as species may be regionally threatened, rare or affected by specific threats that may not act in other parts of the range. To avoid biodiversity loss at the national scale, Red Lists can help to identify species with a high extinction risk. The category Data Deficient is useful to identify research priorities.

Details

Red Lists should follow international standards (IUCN Red List criteria). All species of a given taxonomic group should be assessed (not only species that have been pre-assessed as being threatened). The assessments need to be updated every 10 years to illustrate genuine changes (i.e. changes based upon real changes in status) and non-genuine changes (i.e. changes based upon new information) in conservation status. Red List data should be freely available online.

Status

National Red Lists for butterflies exist for most countries, but are not always up-to-date or just include some highly threatened species. National Red Lists for wild bees exist in several countries, but sometimes only for bumble bees or a few threatened species. For hoverflies, national Red Lists exist only in a few countries.

Action needed

- Fund national Red List projects in European countries

Proposed targets:

i. *National Red Lists available for all European countries* by 2025. Deliverables: Red List assessments of all species in each taxonomic group occurring in the country using the IUCN Red List categories and criteria.

ii. *National Red Lists are updated every 10 years*. Deliverables: Updated Red List assessments of all species of the taxonomic group occurring in the country using the IUCN Red List categories and criteria.

Estimated costs:

iii. *National Red List project*: €50,000 per species group and country.

iv. *National Red List updates:* €50,000 per species group and country.

7.3 Pathways and options for data capture, validation, analysis and storage for a Minimum Viable Scheme

The aims of this section are to: (i) propose pathways for Member States with current capacity below that needed for a Minimum Viable Scheme (MVS) to reach it in the short-term and long-term; (ii) assess the different options for processing, and long-term storage needs for materials caught in traps, so that they can be used in future for morpho- or DNA-taxonomy; and, (iii) assess the options for the data capture, validation, analysis and storage.

7.3.1 Pathways to increase capacity for a pollinator monitoring scheme

The European pollinator monitoring Core Scheme will consist of a professional scheme using pan traps and transects (section 7.3.1.1) as well as a voluntary pillar based upon transect counts (section 7.3.1.2). Three core taxonomic groups will be included: butterflies (with very good taxonomic resources and capacity available, section 7.1.3), hoverflies and wild bees (the latter both with limited taxonomic resources and capacity, sections 7.1.2 and 7.1.2). Moths, as well as rare and threatened species, may be considered as modular add-ons (section 5.3.3) to the Core Scheme (with intermediate taxonomic knowledge available). The proposed pathways to increase the capacity of Member States with current capacity below that needed for a MVS need to consider capacity building for both professional entomologists and amateurs. The skills required for a monitoring scheme include methodological knowledge (e.g. how to install traps or perform transect counts), how to prepare and identify the samples, and how to submit the data. The text below is, therefore, structured around the key questions of how the work will be performed. The general approach on how to increase taxonomic capacity is covered in section 7.2.

7.3.1.1 Professional pillar

Who will conduct the field work (set up and collect traps)?

Installing traps is generally not difficult and just requires some simple basic training. This can be undertaken by amateurs as well as experts, but it needs to be standardised at the European level. In the short term the trapping could be commissioned, but in the long term it is recommended to be organised and performed (or supervised) by national monitoring centres.

Where will the samples be processed?

In the long term, all samples should be processed and stored in a central national facility (e.g. a monitoring centre). Currently, such facilities are lacking in most countries, and so this work could be done by existing institutes (e.g. museums, universities), which could also act as regional centres (e.g. for neighbouring countries). It is recommended that storage is undertaken in the national centres in the long term.

Who will process and identify the samples?

In the long term, experts in the national monitoring centre will identify the samples. Preparation (pinning) could be done by volunteers and field teams that do not need to have strong taxonomic knowledge (e.g. technicians), but need detailed training in preparation and labelling. In the short term, experts of regional centres or consultants could prepare and identify samples. A European-wide identification and storage is not considered feasible, however, as the number of samples will be too high, posing many logistical and technical challenges.

How will the data be submitted and stored?

Data needs to be submitted or shared in a standardised form via an online platform to a European coordination facility, where pan-European analyses are made (see sections 6.1 and 6.2). Each national monitoring facility should have its own interface to validate or correct data from the respective country. Each step of data entry, correction and validation, needs to be thoroughly documented. All data should be open access (CC0 or CC BY-NC licence) at capture resolution (but might be provided with lower resolution if sensitive data is included, such as species with high threat status). All data should be mirrored on several servers to avoid any loss of data.

Where will the monitoring programme be coordinated and data analysed?

A central European facility for data storage and analysis would be needed in the short term. This could potentially be hosted by the European Environmental Agency, European Commission (DG ENV), JRC or Eurostat; ideally a European Centre for Biodiversity

Monitoring would be established, which could also fulfil other tasks. The tasks of such a centre would ideally include, most, if not all of the following, though other organisations may lead on different tasks in coordination with such a centre:

Coordinating national monitoring efforts and promoting and collaborating with voluntary monitoring programmes (e.g. eBMS),

- Writing and disseminating guidelines for both professional and voluntary monitoring,
- Instigating and coordinating the development of new taxonomic tools,
- Coordinating and organising training courses,
- Providing an online platform for data submission,
- Storing and maintaining data,
- Analysing data as a yearly report (as well as special reports for specific purposes),
- Disseminating results and providing information for the public,
- Serving as a central European focal point for pollinator conservation,
- Facilitating and coordinating targeted monitoring of threatened pollinator species,
- Developing guidance to improve the status of pollinators,
- Providing advice to local stakeholders and collaborating with pollinator conservation practitioners.

How will samples be stored?

Samples need to be stored for the long term as taxonomic changes are likely to occur in the future and retrospective analyses should be possible (e.g. to allow DNA barcoding or analyses of intraspecific genetic diversity or pollen loads). Traditional collections of pinned specimens with labels of collection date and locality (ideally coordinates) are suitable for both purposes. This requires the creation of modern entomological collection facilities (i.e. cooled rooms with roller-racking compactors), ideally in the national monitoring centres.

Summary of the pathways:

Short-term: Countries with low capacity would contract persons to install the traps and collect the samples, which would then be transferred (well labelled and ideally pinned) to a regional (or national) monitoring facility, where they would be identified (which could also be by contract). The data would be submitted or connected to the European database and will be accessible also from outside.

Long-term: Countries could build national monitoring centres, which coordinate the sampling and have sufficient entomological staff to identify and store the samples. Such centres could also organise the identification courses for (future) staff to increase capacity. At the European level, a European facility is needed to coordinate national and voluntary efforts, provide taxonomic and methodological guidance, maintain and analyse the European data and serve as a central European focal point for pollinator biodiversity conservation. This role could ideally be focused in a European centre for biodiversity conservation, but in the short term it may be implemented in existing structures (e.g. DG ENV, European Environmental Agency or JRC).

7.3.1.2 Voluntary pillar

Who will coordinate the voluntary monitoring?

Voluntary monitoring needs good coordination and mentoring. National coordination would be required in each Member State (as well as at a European level). Rather than re-inventing the wheel, it will be useful to build upon the existing structures (e.g. eBMS, section 1.2.2). Close collaboration with such existing voluntary schemes is essential. In cases where national coordination is lacking, it would be important to identify a national facility (e.g. NGO, university, institute etc.) to fill this role, or build a new one if necessary (e.g. the national monitoring centre).

How will volunteers be recruited?

Several pathways are useful to recruit volunteers: articles in newspapers, magazines, social media, news stories in TV and radio, information events and excursions (which may be led by the national coordination group). Target audiences include naturalists (e.g. birders), NGOs, existing voluntary recorder schemes, and outdoor communities. Countries with well-established voluntary monitoring schemes (or a European monitoring facility) would need to provide support for countries needing to strengthen their volunteer base. Potential volunteers need to be informed what they will receive in terms of support, such as training, equipment etc.

How will volunteers be trained?

Training courses are essential to ensure standardised data acquisition. Such training is already provided by eBMS for butterflies. Furthermore, there is good training material available online to help beginners. Training courses need to be organised in all countries (or regions), which should not only include taxonomic training, but also training in the methods (section 7.2).

How will the data be submitted by volunteers?

It will be important to build on existing systems (e.g. the eBMS system[187]), which have been developed and improved over several years, rather than developing new ones. National coordination groups would need to use the same systems to facilitate integration of data from several countries. Ideally, data would be submitted to a European database with national coordination groups having access to it. Each national monitoring centre or coordination group would only be able to alter data from their own country. Furthermore, each data change would need to be properly documented to track modifications. Providing different permission levels would ensure that not all staff have access to all stages of data submission and storage.

Summary of the pathways:

National coordination groups would need to be established in countries which have no voluntary monitoring systems in place already. This process would need to be coordinated by a European facility (similar to eBMS). Targeted use of a wide range of media would be needed to identify and recruit interested volunteers. Training courses (preferably locally hosted) would be needed to train volunteers in the monitoring method and identification processes. It would be necessary to establish systems to transfer data to a central European facility (based upon existing ones).

7.3.2 Options for processing and long-term storage of samples

Background

To fully utilise monitoring data, information on species identities and abundances is essential. This requires proper identification by well-trained taxonomic experts and validation mechanisms. Long-term storage of samples is important for future analyses, including verification of doubtful identifications, retrospective adaptation to taxonomic changes and exploitation of new or added value approaches (e.g. identification of pollen loads). Long-term storage is also required to facilitate morphological analyses as well as DNA barcoding.

Considerations

Wet material, such as that removed from pan traps, is often difficult to identify (particularly for wild bees). For proper morphological identification, material needs to be pinned (and in some cases genitalia needs to be dissected). For DNA-barcoding, storage in freezers, ethanol p.a. or buffers is known to be more appropriate, but currently taxon sampling for DNA barcoding and available barcodes in libraries are not sufficient to fully rely on this method. DNA barcodes are missing for many European pollinator species (particularly in wild bees and hoverflies, section 7.2.4). While it is possible to apply metabarcoding and use OTUs (operational taxonomic units) rather than species names, this does not allow data to be linked to species qualities (such as pollination efficacy, conservation status, endemism, ecological specialisation) and also does not distinguish native from invasive species. Furthermore, DNA metabarcoding does currently not allow researchers to quantify species abundances (although some initial studies suggest that this is possible in principle). Even though not ideal for genetic studies, pinned dry samples usually maintain sufficient DNA for simple barcoding analyses (as long as they have not been treated with chemicals). Identification needs to be done by well-trained experts, but pre-sorting morphotypes by volunteers or technicians without detailed taxonomic skills could be an efficient approach.

187 https://butterfly-monitoring.net/

Recommendations for processing and long-term storage of samples

Samples from traps will be wet (i.e. in ethanol) and could be transferred in this condition to national monitoring centres, where they would be pinned and pre-sorted by morphotypes. Alternatively, samples could be pinned and pre-sorted by the local monitoring collaborator and transferred as pinned specimens. In both cases, proper labelling must be ensured and protocols to avoid errors need to be established. By-catch of other taxonomic groups could be stored in 99% ethanol in bulk (sorted by location and date and properly labelled). Identification should be done by taxonomic experts in the national monitoring facilities. In the short term this could be done by contracting consultant taxonomists. A proportion of identified specimens should be cross-identified by other experts (e.g. consultants) for quality assurance checking. Long-term storage should be done in, or close to, the national monitoring centres (e.g. in an affiliated museum), ideally as a pinned and labelled collection, which allows morphological identification (and is sufficiently suitable for DNA barcoding). Using small parts (like single legs) is usually sufficient for DNA barcoding.

7.3.3 Options for data capture, validation and storage

Background

To assure high quality monitoring data, procedures of data capture, validation and storage are essential. It is useful to rely on experiences from existing monitoring programmes (e.g. eBMS) and exploit best practice examples.

Data capture

It will be crucial to use a standard submission system across Europe. Ideally, all data will be submitted to a central European database and each national monitoring centre should have its own interface to validate or correct data from the respective country. A good national example is the British Indicia database system[188], which is built on a PostgreSQL/PostGIS database. For instance, UK Pollinator Monitoring Scheme (section 1.2.3) survey data is extracted directly from this master database using appropriate SQL queries. This data capture system helps minimise errors, for example, by enabling accurate location of plots using GIS mapping and entry of species' names via drop down lists with currently approved nomenclature. Data are submitted via the iRecord website[189]. Original data collection could be done by using a mobile device App or in an Excel sheets (with the drop-down options mentioned above). It needs to be ensured that the submission of data (and metadata) is standardised, and that any submissions (and corrections) of data are properly documented and stored.

Validation

Both volunteer and professional data should be validated by the national coordination group. Trap data should be validated within national monitoring facilities (see above). As a second step, a validation procedure would be implemented at the European level (by a European monitoring facility) and queries would be submitted back to the national centres. Volunteers could submit photographs showing some examples of insect groups with the associated identification (as in the UK PoMS). These photographs would be checked by experts (trained staff at the national monitoring centres). This would allow for quantification of the identification error rates. Clear validation rules would need to be established, and each species record could be flagged with a traffic-light system. These rules should consider, for example: (i) distribution of the taxon (records from outside the known range of a taxon should automatically be flagged in red); (ii) the commonness of the taxon (species would be given regional rarity scores and records of very rare species flagged red, rare species yellow, common species green); (iii) phenology (records outside the typical season of a species should be flagged in red, at the edge of the season in yellow); and, (iv) the experience of the recorder (records of beginners should be flagged in yellow). All records with a red flag would be validated (based upon the provision of photos or other materials). For records flagged in yellow, a random subset could be validated. Beginners should aim at providing photos for all species they have recorded: more experienced recorders should provide photos of species flagged in yellow and red. Data sets with high error rates would be reviewed and could be discarded from the global data set, and the observer asked to attend a training course.

Timeline

Timeliness is of critical importance in this process. Pan-European validated data sets would ideally be available one year after the monitoring period. To reach this, the national monitoring centres would need to provide sufficient entomological personnel and resources. To achieve this annual turnaround, the following timeline would need to attain:

- Year 1 March to October: data acquisition in the field (this season will be shorter in the North than in the South of Europe).
- Year 1 October to year 2 March: species identifications completed

188 www.indicia.org.uk
189 https://www.brc.ac.uk/irecord/poms-fit-count

- Year 2 March to April: Data validation and submission
- Year 2 May to June: Pan-European analyses and publication

To ensure timely publication, sufficient entomological personnel would be required within countries, particularly in the national monitoring centres.

Recommendations for analysis, data storage and access to data

Pan-European data analyses should be made by a European facility, but the data should remain open access, so that analyses on a country or regional level are also possible. A central European facility for data storage is needed in the short term (with mirror servers). All data should be open access (CC0 or CC-BY licence) at capture resolution (but might be provided with less resolution if sensitive data is included). A DOI for each dataset is useful to ensure attribution and tracking of its use, via citation and acknowledgement of the originators. Volunteers and other stakeholders (e.g. landowners with monitoring sites) should receive annual summary reports to help facilitate participation. In the UK PoMS, reports provide a list of the (verified) bee and hoverfly species found on each 1 km square, summarised in the context of the national-scale findings.

7.3.4 Key issues for data ownership

For elements of the pollinator monitoring where contributors are paid, open access data should be mandated from the outset with a CC-BY 4.0 licence as a minimum standard. For elements that involve volunteer contributions, either by recorders or regional co-ordinators (e.g. citizen science components), a flexible approach to data ownership is likely to be required. This is particularly the case for existing initiatives that may contribute to the EU Pollinator Monitoring Scheme, such as existing Butterfly Monitoring Schemes that are partners in the eBMS. National Butterfly Monitoring Schemes retain ownership of data from their networks, but collaborate with other schemes as part of the eBMS, to further use the data for research and policy use, for example in the production of EU biodiversity indicators. The eBMS has established a data access policy and data licence for use of the data[190] and this could be used to help inform the approach of the EU-PoMS. Such an agreement ensures due acknowledgement of national schemes and enables input into appropriate use of the data.

In volunteer-based monitoring schemes, the volunteers remains the owner of the data, but give organisations (e.g. eBMS, and in the future the EU-PoMS) the right to use the data. They also have the right to be removed from the monitoring scheme (i.e. their personal data), but the species data is not removed. For targeted monitoring, separate arrangements on data ownership would be needed. Individual monitoring data should not be published or forwarded without the volunteer's consent, while processed products may be published or forwarded. In cases where third parties are involved (e.g. an administration giving access to a protected area), they should be made a co-owner of the data.

For all monitoring schemes, we recommend that recorders are clearly informed upfront that their data will be made publically available and used to generate reports and trend analyses. The monitoring data should also be converted to species records to inform distribution databases (e.g. GBIF and national biodiversity systems). Data should be available as open access as far as possible (at least as CC-BY 4.0). As a general principle, data ownership shall be retained for onward data flow (i.e. for data analyses at the national level and for EU-level reporting and indicators).

In addition to the monitoring data, personal data of voluntary recorders will need to be stored at the national level (particularly name, address and e-mail address) to allow them to be contacted. These data need to be stored in a secure manner and conform to GDPR. A reference number should be provided with the data together with the name of the institute that has the full address information.

References

Abadjiev S (1993a) Butterflies of Bulgaria, Part 1. Papilionidae & Pieridae. Veren Publishers, Sofia. 91 pp.

Abadjiev S (1993b) Butterflies of Bulgaria, Part 2. Nymphalidae: Libytheinae & Satyrinae. Veren Publishers, Sofia. 127 pp.

Abadjiev S (1995) Butterflies of Bulgaria, Part 3, Nymphalidae: Apaturinae & Nymphalinae. S. Abadjiev, Sofia. 159 pp.

Abadjiev S (2001) An Atlas of the Distribution of the Butterflies in Bulgaria (Lepidoptera: Hesperioidea & Papilionoidea. Zoogeographica Balcanica, Pensoft, Sofia. 335 pp.

190 https://butterfly-monitoring.net/ebms-data%20access

Abafi-Aigner L (1907) Magyarország lepkéi tekintettel Európa többi országainak lepkefaunájára. A Berge-féle lepkekönyv képeivel. Királyi Magyar Természettudományi Társulat, Budapest, XXXI +9: 1037 pp. (reprinted in 2000)

Aguado Martín LO, Fereres Castiel A, Sandoval EV (2015) Guía de campo de los polinizadores de España. Mundiprensa: 364 pp.

Amiet F, Herrmann M, Müller A, Neumeyer R (2001) Apidae 3: *Halictus*, *Lasioglossum*. Fauna Helvetica 6. CSCF & SEG, Neuchâtel. 208 pp.

Amiet F, Herrmann M, Müller A, Neumeyer R (2004) Apidae 4: *Anthidium*, *Chelostoma*, *Coelioxys*, *Dioxys*, *Heriades*, *Lithurgus*, *Megachile*, *Osmia*, *Stelis*. Fauna Helvetica 9. CSCF & SEG, Neuchâtel. 277 pp.

Amiet F, Herrmann M, Müller A, Neumeyer R (2007) Apidae 5: *Ammobates*, *Ammobatoides*, *Anthophora*, *Biastes*, *Ceratina*, *Dasypoda*, *Epeoloides*, *Epeolus*, *Eucera*, *Macropis*, *Melecta*, *Melitta*, *Nomada*, *Pasites*, *Tetralonia*, *Thyreus*, *Xylocopa*. Fauna Helvetica 20. CSCF & SEG, Neuchâtel. 356 pp.

Amiet F, Herrmann M, Müller A, Neumeyer R (2010) Apidae 6: *Andrena*, *Melitturga*, *Panurginus*, *Panurgus*. Fauna Helvetica 26. SEG & CSCF, Neuchâtel. 316 pp.

Amiet F, Müller A, Praz C (2017) Apidae 1: *Apis*, *Bombus*. Fauna Helvetica 29. SEG CSCF, Neuchâtel. 188 pp.

Amiet F, Neumeyer R, Müller A (1999) Apidae 2: *Colletes*, *Dufourea*, *Hylaeus*, *Nomia*, *Nomioides*, *Rhophitoides*, *Rophites*, *Sphecodes*, *Systropha*. Fauna Helvetica 4. CSCF und SEG, Neuchâtel. 239 pp.

Bálint Z (1996) A Kárpát-medence nappali lepkéi. 1. rész. Magyar Madártani és Természetvédelmi Egyesület, Budapest. 183 pp.

Bálint Z, Gubányi A, Pitter G (2006) Magyarország védett pillangóalakú lepkéinek katalógusa a Magyar Természettudományi Múzeum gyűjteménye alapján. 136 pp.

Ball SG, Morris RKA (2014) A review of the scarce and threatened flies of Great Britain. Part 6: Syrphidae. Species Status 9: 1–130 Joint Nature Conservation Committee, Peterborough.

Ball SG, Morris RKA (2015) Britain's Hoverflies: A field guide. Princeton University Press, 2nd ed. 312 pp.

Ball SG, Morris RKA, Rotheray G, Watt K (2011) Atlas of the hoverflies of Great Britain (Diptera, Syrphidae). Wallingford: Biological Records Centre. 183 pp.

Balletto E, Bonelli S, Cassulo LA (2007) Insecta Lepidoptera Papilionoidea. In Ruffo S, Stoch F (eds) Checklist and Distribution of the Italian Fauna.: 10.000 Terrestrial and Inland Water Species, Vol. 17. Memorie del Museo Civico di Storia Naturale di Verona, Verona, Italy. 257–261.

Ban-Calefariu C (2009) Megachilidae şi Anthophoridae (Apoidea) din fauna României. Editura ALTIP. 300 pp.

Bankowska R (1967) Materiaux pour l' etude des Syrphides (Diptera) de Bulgarie. Fragmenta Faunistica 13: 345–389.

Bartsch H, Binkiewicz A, Klintbjer A, Radén A, Nasibov E (2009a) Nationalnyckeln till Sveriges flora och fauna DH. 53a. Tvåvingar. Blomflugor I: Diptera: Syrphidae: Syrphinae. Artdatabanken, Uppsala. 406 pp.

Bartsch H, Binkiewicz A, Radén A, Nasibov E (2009b) Nationalnyckeln till Sveriges flora och fauna DH. 53b. Tvåvingar. Blomflugor II: Diptera: Syrphidae: Eristalinae & Microdontinae. Artdatabanken, Uppsala. 478 pp.

Bastian O (1994) Schwebfliegen – Syrphidae. Spektrum Verlag. 168 pp.

Belakova A (1996) Prehl'ad ohrozenych vzacnych druhov vciel na slovensku. Survey of threatened and rare species of bees in Slovakia. Folia Faunistica Slovaca, 1: 53–58.

Bělín V (1999) Motýli České a Slovenské Republiky Aktivní ve Dne. Pensoft. 172 pp.

Beneš J, Konavička M, Dvořák J, Fric Z, Havelda Z, Pavlíčko A, Vrabec V, Weidenhoffer Z (2002) Motýli České republiky: Rozšíření a ochrana I, II: Praha: SOM. 857 pp.

Bengtsson BÅ, Gustafsson B, Palmqvist G (2016) Katalog över svenska fjärilar. Uppdaterad juni 2016 med fynd publicerade i Entomologisk Tidskrift 137: 13–30 & 39–50.

Berland L (1999) Hyménoptères de France, Part 2 Scolioides: Formicoides, Pompiloides, Vespoides, Sphécoides, Apoides. Editions N. Boubée. 198 pp.

Bertollo S, Sommaggio D (2012) Riconoscere i Sirfidi: la chiave dicotomica ai generi italiani. Quaderni Stazione di Ecologia Museo civico di Storia Naturale di Ferrara 20: 101–145.

Bos F, Bosveld M, Groenendijk D, van Swaay C, Wynhoff I, (2006) De Dagvlinders van Nederland. KNNV. 400 pp.

Bot S, van de Meutter F (2019) Veldgids Zweefvliegen. KNNV Publishing

Bothe G (1996) Schwebfliegen. Deutscher Jugendbund für Naturbeobachtungen (DJN). 123 pp.

Brâdescu V (1991) Les Syrphides de Roumanie (Diptera: Syrphidae). Clés de determination et repartition. Travaux du Muséum National d'Histoire naturelle 'Grigore Antipa' 31: 7–83.

Burgio S, Sommaggio D, Birtele D (2015) I Sirfidi (Dittei): biodiversità e conservazione. Manuale operativo. ISPRA, Manuali e Linee Guida 128: 182 pp.

Buszko J (1997) Atlas rozmieszczenia motyli dziennych w Polsce. Turpress, Toruń. 170 pp.

Buszko J, Masłowski J (2015) Motyle dzienne Polski. Wydawnictwo Koliber, Nowy Sącz. 274 pp.

Bygebjerg R (2004) http://bios.au.dk/raadgivning/natur/redlistframe/artsgrupper/

Dincă V, Montagud S, Talavera G, Hernández-Roldán J, Munguira ML, García-Barros E, Hebert PDN, Vila R (2015) DNA barcode reference library for Iberian butterflies enables a continental-scale preview of potential cryptic diversity. Scientific Reports 5:12395

DNFC (2010) A guide to the butterflies of Ireland. Dublin Naturalists' Field Club.

Ebert G, Rennwald E (1993a) Die Schmetterlinge Baden-Württembergs, Bd.1, Tagfalter. Ulmer. 552 pp.

Ebert G, Rennwald E (1993b) Die Schmetterlinge Baden-Württembergs, Bd.2, Tagfalter. Ulmer. 535 pp.

Eliasson CU, Ryrholm N, Gärdenfors U (2005) Fjärilar, Dagfjärilar. The Encyclopedia of the Swedish Flora and Fauna. ArtDatabanken. 407 pp.

Else GR, Edwards M (2018) Handbook of the Bees of the British Isles. Volumes 1 & 2. The Ray Society, London. 775 pp.

Falk S (1991) A review of the scarce and threatened bees, wasps and ants of Great Britain. Research & survey in nature conservation 35: 344 pp.

Falk S, Lewington R (2015) Field Guide to the Bees of Great Britain and Ireland. British Wildlife Publishing. 432 pp.

Falk S, Lewington R (2017) Bijen Veldgids voor Nederland en Vlaanderen. Kosmos. 444 pp.

Ferretti G (2012) Farfalle delle Alpi: Come Riconoscerle, dove e Quando Osservarle. Blu Edizioni. 350 pp.

Fichefet V, Barbier Y, Baugnée J-Y, Dufrêne M, Goffart P, Maes D, Van Dyck H (2008) Papillons de jour de Wallonie (1985–2007). Publication du Groupe de Travail Lépidoptères Lycaena et du Département de l'étude du milieu naturel et agricole (SPW-DGARNE), série "Faune - Flore - Habitats" 4: 320 pp.

Fitzpatrick Ú., Murray TE, Byrne A, Paxton RJ, Brown MJF (2006) Regional red list of Irish bees. National Parks and Wildlife Service (Republic of Ireland) and Environment and Heritage Service (Northern Ireland), Dublin, Ireland. 38 pp.

Fox R, Brereton TM, Asher J, August TA, Botham MS, Bourn NAD, Cruickshanks KL, Bulman CR, Ellis S, Harrower CA, Middlebrook I, Noble DG, Powney GD, Randle Z, Warren MS, Roy DB (2015) The State of the UK's Butterflies 2015. Butterfly Conservation and the Centre for Ecology & Hydrology, Wareham, Dorset. 28 pp.

García-Barros E, Munguira ML, Cano JM, Benito HR, Garcia-Pereira P, Maravalhas ES (2004) Atlas de la mariposas diurnas de la Península Ibérica e islas Baleares (Lepidoptera: Papilionoidea & Hesperioidea). Monografías SEA 11: 230 pp.

García-Barros E, Munguira ML, Stefanescu C, Vives Moreno A (2013) Lepidoptera Papilionoidea. In: Ramos MA et al. (eds.). Fauna Iberica, vol. 37. Museo Nacional de Ciencias Naturales, CSIC, Madrid. 1213 p.

Gärdenfors U (2010) Rödlistade arter i Sverige - The 2010 Red List of Swedish Species 2010. ArtDatabanken, SLU: Uppsala. 199 pp.

Gergely P, Gór Á, Hudák T, Ilonczai Z, Szombathelyi E (2017) Nappali lepkéink. Határozó terepre és természetfotókhoz. Kitaibel kiadó. 264 pp.

Głowaciński Z, Nowacki J (2009) Polish Red Data Book of Animals. Institute for Nature Conservation, PAS, Krakow. 447 pp.

Gogala A (2014) Čebele Slovenije. Biološki inštitut Jovana Hadžija, Ljubljana: 181 pp.

Gokcezade JF, Gereben-Krenn BA, Neumayer J (2017) Feldbestimmungsschlüssel für die Hummeln Deutschlands, Österreichs und der Schweiz. Quelle & Meyer, Wiebelsheim. 55 pp.

Gozmány L (1968) Nappali lepkék - Diuna. Fauna hungariae 91: 1–204.

Haahtela T, Saarinen K, Ojalainen P, Aarnio H (2006) Päiväperhoset. Suomi - Pohjola - Baltia. Kustannusosakeyhtiö Tammi. 248 pp.

Haahtela T, Saarinen K, Ojalainen P, Aarnio H (2019) Butterflies of Britain and Europe – a photographic guide. Bloomsbury Publishing. 400 pp.

Haarto A, Kahanpää J, Kakko I, Pohjoismäki J, Winqvist K (2019) Kärpäset - True Flies. In: Hyvärinen E, Juslén A, Kemppainen E, Uddström A, Liukko U-M (Eds): Suomen lajien uhanalaisuus. Ympäristöministeriö/Suomen Ympäristökeskus, Helsinki: 532–548.

Haarto A, Kerppola S (2007) Suomen Kukkakärpaset ja lähialueiden lajeja. Suomen ympäristökeskus. 647 pp.

Harding J (2008) Discovering Irish Butterflies and their habitats. J. Hardling. 156 pp.

Hejda R, Farkač J, Chobot K (2017) Červený seznam ohrožených druhů České Republiky bezobratlí. Agentura ochrany přirody a krajiny, Praha. 308 pp.

Hermansen K (2010) Dagsommerfugle I Danmark. Apollo Books. 224 pp.

Holmström G (2007) Humlor: alla Sveriges arter: så känner du igen dem i naturen - och i trädgården. Brutus Östlings bokf Symposion. 159 pp.

Holmström G (2014) Svenska citronbin (*Hylaeus*) – med mask för ansiktet. Entomologisk Tidskrift 135: 1–25.

Iuga VG (1958) Fauna Republicii Populare Romîne, Insecta, vol. IX, fascicula 3, Hymenoptera, Apoidea (familia Apidae, subfamilia Anthophorinae). Editura Academiei Republicii Populare Române. 270 pp.

Ivinskis P, Augustauskas J (2004) Lietuvos dieniniai drugiai. Kaunas: Lututė. 247 pp.

Jakšić P (1988) Provisional distribution maps of the butterlies of Yugoslavia (Lepidoptera, Rhopalocera). Jugoslavensko entomološko društvo, Zagreb. 214 pp.

Kádár M, Petrányi G, Ronkay G, Ronkay L (2010) A magyarországi bagolylepkék (Lepidoptera, Noctuidae) fényképes határozója - A Photographic Identification Guide to the Noctuids (Lepidoptera, Noctuidae) of Hungary, Szalkay József Magyar Lepkészeti Egyesület, Budapest. 72 pp.

Knechtel WR (1955) Fauna R.P.R.: Hymenoptera, Subfam. Apinae. Acad. R.P.R. IX (1), Bucuresti. 111 pp.

Kormann K (2002) Schwebfliegen und Blasenkopffliegen Mitteleuropas: Ein Naturführer zum Bestimmen der wichtigsten Arten. Fauna Naturführer. 272 pp.

Lafranchis T (2004) Butterflies of Europe: Identifying Butterflies is Easy - New Field Guide and Key. Diatheo. 350 pp.

Lafranchis T (2016) Papillons de France. Diatheo. 351 pp.

Leclercq J, Gaspar C, Marchal J-L, Verstraeten C, Wonville C (1980) Analyse des 1600 premières cartes de l'Atlas provisoire des Insectes de Belgique, et première liste rouge d'Insectes menaces dans la faune belge. Notes fauniques de Gembloux 4: 1–104.

Lewington R, Whalley P (2000) The pocket guide to butterflies. Mitchell Beazley. 168 pp.

Lilleleht V (2001) Red Data Book of Estonia. http://vana.elurikkus.ut.ee/prmt.php?lang=eng

Macek J (2015) Motýli a housenky střední Evropy IV. Denní motýli. Academia. 540 pp.

Macek J (2017) Blanokřídlí České republiky I. Žahadloví - II.dotisk. Academia. 524 pp.

Madsen HB (2019) Bier. In Moeslund JE (ed): Den danske Rødliste 2019. Aarhus Universitet, DCE

Maes D, Vanreusel W, Van Dyck H (2013) Dagvlinders in Vlaanderen: nieuwe kennis voor betere actie. Uitgeverij Lannoo nv, Tielt. 542 pp.

Maes D, Verovnik R, Wiemers M, Brosens D, Beshkov S, Bonelli S et al (2019) Integrating national Red Lists for prioritising conservation actions for European butterflies. Journal of Insect Conservation 23: 301–330.

Makris C (2003) Butterflies of Cyprus. Bank of Cyprus. 329 pp.

Maravalhas E (2003) As Borboletas de Portugal. Edições Vento Norte. 455 pp.

Marttila O, Saarinen, K., Aarnio, H., Haahtela, T. & Ojalainen, P. 2000. Päiväperhosopas. Suomi ja lähialueet. Kustannusosakeyhtiö Tammi, Helsinki.

Mazánek L, Barták M (2005) Syrphidae. In: Farkač J, Král D, Škorpík M (eds.) Červený seznam ohrožených druhů České republiky. Bezobratlí. Red list of threatened species in the Czech Republic. Invertebrates. Agentura ochrany přírody a krajiny ČR, Praha: 300–303.

Michez D, Rasmont P, Terzo M, Vereecken NJ (2019) Bees of Europe. NAP Editions. 548 pp.

Móczár M (1957) Méhfélék – Apidae. Fauna Hungariae 19: 1–76.

Móczár M (1958) Müvészméhek – Megachilidae. Fauna Hungariae 35: 1–78.

Móczár M (1960) Ösméhek, földi méhek – Colletidae, Melittidae. Fauna Hungariae 51: 1–64.

Móczár M (1967) Karscú méhek – Halictidae. Fauna Hungariae 85: 1–116.

Monsevičius V (1995) A checklist of wild bee species (Hymenoptera, Apoidea) of Lithuania with data to their distribution and bionomics. In: New and rare for Lithuania insect species: records and descriptions of 1994–1995. Institute of Ecology, Vilinus. 7–144.

Mossberg B, Cederberg B (2012) Humlor i Sverige. Bonnier fakta, Stockholm. 191 pp.

Nash D, Boyd T, Hardiman D (2010) Ireland's Butterflies – a review. Dublin Naturalists' Field Club, Dublin. 272 pp.

Newland DE, Still R, Swash A, Tomlinson D (2015) Britain's Butterflies: A Field Guide to the Butterflies of Britain and Ireland. 3rd Ed. Princeton University Press. 240 pp.

Nieto A, Roberts SPM, Kemp J, Rasmont P, Kuhlmann M, García Creado M, Biesmeijer JC, Bogusch P, Dathe HH et al. (2014) European Red List of bees. Luxembourg: Publication Office of the European Union. 96 pp.

Nieuwenhuijsen H, Peeters T (2016) Nederlandse Bijen Deel 1. Jeugdbondsuitgeverij. 172 pp.

Objectiu Natura (2012) Mariposas por la vida. Guía visual de las mariposas ibéricas diurnas. Gráficas Iomagar, Barcelona. 255 pp.

Ortiz-Sánchez FJ, Gallego CO (2004) Fauna Ibérica. Vol. 23, Hymenoptera: Apoidea I. Fauna Ibérica 23: 560 pp.

Õunap E, Tartes U (2014): Eesti päevaliblikad. Varrak, Tallinn. 320 pp.

Pamperis LN (2009) The butterflies of Greece. Edition Pamperis. 766 pp.

Parkkinen S, Paukkunen J, Teräs I (2018) Suomen kimalaiset. Docendo Oy, Jyväskylä. 176 pp.

Paukkunen J, Paappanen J, Leinonen R, Punttila P, Pöyry P, Raekunnas M, Teräs I, Vepsäläinen K, Vikberg V (2019) Stinging wasps, bees and ants. In: Hyvärinen E, Juslén A, Kemppainen E, Uddström A, Liukko U-M (eds.) The 2019 Red List of Finnish Species. Ministry of the Environment & Finnish Environment Institute. Helsinki: 451–465. https://punainenkirja.laji.fi/en

Pavelka M, Smetana V (2000) Čmeláci. Metodika ČSOP. 105 pp.

Peeters TMJ, Nieuwenhuijsen H, Smit J, van der Meer F, Raemakers IP, Heitmans WRB, van Achterberg K, Kwak M, Loonstra AJ, de Rond J, Roos M, Reemer M (2012) De Nederlandse Bijen (Hymenoptera: Apidae S.L.). Natuur van Nederland 11. Naturalis Biodiversity Center, Leiden. 544 pp.

Pekkarinen A, Teräs I (1977) Suomen kimalaisista ja loiskimalaisista. Luonnon Tutkija 81: 1–24.

Polak S (2009) Metulji Notranjske in Primorske. Notranjski muzej, 180 pp.

Potts SG, Vulliamy B, Roberts SPM, O'Toole C, Dafni A, Ne'eman G, Willmer P (2005) Role of nesting resources in organising diverse bee communities in a Mediterranean landscape. Ecological Entomology 30: 78–85.

Quaranta M (2019) Diagnostic keys of wild bee morphogenera. CREA, Bologna

Quaranta M, Cornalba M, Biella P, Comba M, Battistoni A, Rondinini C, Teofili C (2018) Lista rossa IUCN delle api italiane minacciate. Comitato Italiano IUCN e Ministero dell'Ambiente e della Tutela del Territorio e del Mare, Roma.

Rákosy L (2013) Fluturii diurni din România. Cunoaştere, protecție, conservare. 352 pp.

Rákosy L, Goia M, Kovács Z (2003) Catalogul Lepidopterelor României. Societatea Lepidopterologică Romană, Cluj-Napoca, 447 pp.

Rasmont P, Devalez J, Pauly A, Michez D, Radchenko V (2017) Addition to the checklist of IUCN European wild bees (Hymenoptera: Apoidea). Annales de la Société entomologique de France (N.S.) 53: 17–32.

Rasmussen C, Schmidt HT, Madsen HB (2016) Distribution, phenology and host plants of Danish bees (Hymenoptera, Apoidea). Zootaxa 4212: 1–100.

Rašomavičius V (2007). Red Data Book of Lithuania (Lietuvos Raudonoji Knyga). Ministry of Environment of the Republic of Lithuani: Vilnius. 800 pp.

Red Data Book of Estonia (2008) Commission for Nature Conservation of the Estonian Academy of Sciences. http://elurikkus.ut.ee/prmt.php?

Reemer M, Renema W, van Steenis W, Zeegers T, Barendregt A, Smit JT, van Veen MP, van Steenis J, van der Leij LJJM (2009) De Nederlandse zweefvliegen. Nederlandse Fauna 8. KNNV. 450 pp.

Reemer M (2018) Basisrapport voor de Rode Lijst Bijen. EIS Kenniscentrum Insecten, Leiden. 174 pp.

Reichl, ER (1992) Verbreitungsatlas der Tierwelt Österreichs. Band 1: Lepidoptera - Diurna. Forschungsinstitut für Umweltinformatik, Linz. 114 + 10 pp.

Reinhardt et al. (in press) Verbreitungsatlas der Tagfalter und Widderchen Deutschlands. Ulmer

Saarinen K, Jantunen J (2013) Päiväperhoset matkalla pohjoiseen. Hyönteistarvike TIBIALE Oy, Helsinki. 248 pp.

Sárospataki M, Novák J, Molnár V (2005) Assessing the Threatened Status of Bumble Bee Species (Hymenoptera: Apidae) in Hungary, Central Europe. Biodiversity and Conservation 14: 2437–2446.

Scheuchl E (2000) Illustrierte Bestimmungstabellen der Wildbienen Deutschlands und Österreichs. Band I: Anthophoridae. 2. Auflage. Eigenverlag: 158 pp.

Scheuchl, E (2006) Illustrierte Bestimmungstabellen der Wildbienen Deutschlands und Österreichs. Band II: Megachilidae - Melittidae. Eigenverlag. 192 S.

Schmid-Egger C, Scheuchl E (1997): Illustrierte Bestimmungstabellen der Wildbienen Deutschlands und Österreichs unter Berücksichtigung der Arten der Schweiz. Band III. Monografien Entomologie Hymenoptera 30: 180 pp.

Settele J, Steiner R, Reinhardt R, Feldmann R, Hermann G (2015) Schmetterlinge – Die Tagfalter Deutschlands (3. Aufl.). Ulmer. 256 pp.

Sielezniew M, Dziekańska I (2010) Motyle dzienne. Multico Oficyna Wydawnicza, Warszawa. 336 pp.

SLU Artdatabanken (2020). Red listed species in Sweden 2020. SLU, Uppsala

Smit JT, Kalkman VJ, de Rond J (2018) Basisgids Hommels. EIS Kenniscentrum Insecten, Leiden. 58 pp.

Söderman G, Leinonen R (2003) Suomen mesipistiäiset ja niiden uhanalaisuus. Tremex Press Oy, Helsinki. 420 pp.

Söderström (2013) Sveriges Humlor – en Fälthandbok. Entomologiska föreningen, Stockholm. 127 pp.

Sommaggio D (2005) Insecta Diptera Syrphidae (Syrphinae, Syrphini). In: Ruffo S, Stoch F (eds) Checklist and distribution of Italian fauna. Memorie del Museo Civico di Storia Naturale di Verona. 2Serie. Sezione Scienze della Vita 16: 245–246.

Speight MCD (2008) Database of Irish Syrphidae (Diptera). Irish Wildlife Manuals 36: National Parks and Wildlife Service, Department of Environment, Heritage and local government. 338 pp.

Speight MCD (2016) StN key for the identification of the genera of European Syrphidae 2016. Syrph the Net, the database of European Syrphidae (Diptera) 90: 42 pp.

Speight MCD (2020) Species accounts of European Syrphidae, 2020. Syrph the Net, the database of European Syrphidae (Diptera), vol. 104, Syrph the Net publications, Dublin, 314 pp.

Speight MCD, Sarthou J-P (2017) StN keys for the identification of the European species of various genera of Syrphidae 2017. Syrph the Net, the database of European Syrphidae (Diptera) 99: 139 pp.

Spuris Z (1998) Red Data Book of Latvia. Vol. 4. Invertebrates. Riga, 388 pp.

Ssymank A, Doczkal D, Rennwald K, Dziock F (2011): Rote Liste und Gesamtartenliste der Schwebfliegen (Diptera: Syrphidae) Deutschlands (2. Fassung, Stand April 2008). In: BfN (ed.) Rote Liste gefährdeter Tiere, Pflanzen und Pilze Deutschlands. Band 3: Wirbellose Tiere (Teil 1). Naturschutz und biologische Vielfalt 70: 13–83.

Stettmer C, Bräu M, Gros P, Wanninger O (2007) Die Tagfalter Bayerns und Österreichs. 2nd Ed. Bayerische Akademie für Naturschutz und Landschaftspflege. 248 pp.

Stubbs AE, Falk SJ (2002) Britisch Hoverflies: An illustrated identification guide. British Entomological & Natural History Society, 2nd ed. 469 pp.

Tamutis V, Straigis J, Amšiejus A (2010) Kamanės. Lututė, Kaunas. 74 pp.

Thomas J, Lewington R (2014) Butterflies of Britain & Ireland. British Wildlife Publications. 288 pp.

Thompson FC, Rotheray G (1998) Family Syrphidae. In: Papp L, Darvas B (eds): Manual of Palaearctic Diptera. Vol 3. Science Herald, Budapest: 81–139.

Tiitsaar A, Valdma D, Õunap E, Remm J, Teder T, Tammaru T (2019) Distribution of butterflies (Lepidoptera: Papilionoidea) in Estonia: Results of a systematic mapping project reveal long-term trends. Annales Zoologici Fennici 56: 147–185.

Tolman T (2009) Collins Butterfly Guide: The Most Complete Field Guide to the Butterflies of Britain and Europe. Harper Collins. 384 pp.

Tolman T, Lewington R (2015) Guide Delachaux des papillons de France. Delachaux. 224 pp.

Tomozei B (2000) Cuckoo bumblebees from Romania. Ion Borcea, Bacău.

Torp E (1984) De danske svirrefluer (Diptera: Syrphidae). Danmarks Dyreliv I. Bauna Boger. 300 pp.

Torp E (1994) Danmarks svirrefluer (Diptera: Syrphidae). Apollo Books, Stenstrup. 490 pp.

Tóth S (2011): Magyarország zengőlégy faunája (Diptera: Syrphidae) – Howerfly fauna of Hungary (Diptera: Syrphidae). E-Acta Naturalia Pannonica Suppl. 1: 387 pp.

Tóth B (2019) Magyarország nagylepkéinek határozója - Identification book of Macrolepidoptera of Hungary, Magyar Biológiai Társaság, 315 pp.

Tshikolovets VV (2011) Butterflies of Europe and the Mediterranean area. Tshikolovets. 544 pp.

Van Breugel P (2019) Basisgids Wilde bijen. KNNV. 176 pp.

Van Swaay C, Cuttelod A, Collins S, Maes D, Munguira ML, Šašić M, Settele J, Verovnik R, Verstrael T, Warren M, Wiemers M, Wynhoff I (2011) European Red List of Butterflies. Publications Office of the European Union. 48 pp.

Van Veen MP (2010) Hoverflies of Northwest Europe: Identification keys to the syrphidae. KNNV Publishing. 248 pp.

Varga Z (1984) Busalepkék - szemeslepkék. In: Móczár L (ed) Állathatározó. Tankönyvkiadó, Budapest: 129–152

Varga Z (1989) Lepkék (Lepidoptera rendje. [Ordo Lepidoptera.]. In: Rakonczy Z (ed.) Vörös könyv. A Magyarországon kipusztult és veszélyeztetett növény- és áltafajok. AKadémia kiadó, Budapest: 189–244

Verdú JR, Galante E (2006) Libro Rojo de los Invertebrados de España. Dirección General para la Biodiversidad, Ministerio de Medio ambiente: Madrid. 211 pp.

Verdú JR, Numa C, Galante E (2011) Atlas y Libro Rojo de los Invertebrados amenazados de España (Especies Vulnerables). Dirección General de Medio Natural y Política Forestal, Ministerio de Medio Ambiente, Medio rural y Marino. 1.318 pp.

Verovnik R, Rebeušek F, Jež M (2012) Atlas dnevnih metuljev (Lepidoptera: Rhopalocera) Slovenije. Center za kartografijo favne in flore, Miklavž na Dravskem polju, 456 pp.

Vujić A, Speight M, de Courcy Williams ME, Rojo S, Ståhls G, Radenković S, Likov L, Miličić M, Pérez Bañón C, Falk S, Petanidou T (2020) Atlas of the hoverflies of Greece. Brill. Leiden, Netherlands. 382 pp.

Westrich P (2019) Die Wildbienen Deutschlands. 2. Aufl. Ulmer. 824 pp.

Westrich P, Frommer U, Mandery K, Riemann H, Ruhnke H, Saure C, Voith J (2011) Rote Liste und Gesamtartenliste der Bienen (Hymenoptera, Apidae) Deutschlands (5. Fassung, Dezember 2011). In: Bundesamt für Naturschutz (Ed.) Rote Liste der gefährdeter Tiere, Pflanzen und Pilze Deutschlands. Band 3: Wirbellose Tiere (Teil 1): 371–416.

Wiemers M, Balletto E, Dincă V, Fric ZF, Lamas G, Lukhtanov V, Munguira ML, van Swaay CAM, Vila R, Vliegenhart A, Wahlberg N, Verovnik R (2018) An updated checklist of the European Butterflies. ZooKeys 811. 9–45.

Wind P, Pihl S (2010) Den danske rødliste. - Danmarks Miljøundersøgelser, Aarhus Universitet,

Wynhoff I, van Swaay CAM, Veling K, Vliegenthart A (2014). De Nieuwe Veldgids Dagvlinders. KNNV Uitgeverij i.s.m. De Vlinderstichting, Zeist/Wageningen. 328 pp.

Appendices

Appendix 7.1. Wild Bee expertise (answers by country)

Austria

General quality of taxonomic knowledge – good

Checklist – Gusenleitner et al. (2012)

Field Guide – none

Online ID tools – none

Atlas – ZOBODAT (privately stored)

Online atlas or recording scheme – none

Handbook or ID keys – Scheuchl (1995, 1996, 2000, 2006), Schmid-Egger & Scheuchl (1997), Warncke (1992), Eßmer (1969, 1970, 1971), Dathe et al. (2016)

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – ca. 15

Meetings / Organisations – NA

Belgium

General quality of taxonomic knowledge – very good

Checklist – http://zoologie.umons.ac.be/hymenoptera/liste_them.asp?them=Belgium

Field Guide – none

Online ID tools – none

Atlas – http://zoologie.umons.ac.be/hymenoptera/liste_them.asp?them=Belgium

Online atlas or recording scheme – Observation.be; www.waarnemingen.be

Handbook or ID keys – for some groups, not comprehensive

National Red List – in press and a first one was published in 1993.

Internet Fora – none

How many species are DNA barcoded – ca. 250

Number of experts – 3 labs + museums

Meetings / Organisations – yes

Bulgaria

General quality of taxonomic knowledge – poor

Checklist – Atanassov (1962, 1964 1972); Ljubomirov (in prep.), some regional faunistic works

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – ca. 20

Number of experts – 0–1

Meetings / Organisations – NA

Croatia

General quality of taxonomic knowledge – poor

Checklist – none

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – none

Meetings / Organisations – NA

Cyprus

General quality of taxonomic knowledge – medium

Checklist – Varnava (submitted)

Field Guide – none

Online ID tools – www.wildbeesofcyprus.org

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – two

Meetings / Organisations – NA

Czech Republic

General quality of taxonomic knowledge – very good

Checklist – Bogusch et al. (2007)

Field Guide – Macek (2017)

Online ID tools – none

Atlas – Macek (2017)

Online atlas or recording scheme – none

Handbook or ID keys – German keys and Fauna Helvetica

National Red List – Hejda et al. (2017): http://www.ochranaprirody.cz/res/archive/372/058766.pdf?seek=1509546816

Internet Fora – Facebook (Blanokřídlí České republiky, Určování bezobratlých)

How many species are DNA barcoded – a high proportion

Number of experts – ca. 6

Meetings / Organisations – yearly meeting of Czech and Slovak hymenopterists: http://hymenoptera.wz.cz/

Denmark

General quality of taxonomic knowledge – good

Checklist – Madsen et al. (2016)

Field Guide – none

Online ID tools – none

Atlas – Rasmussen et al. (2016)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – Wind & Pihl (2010); a new one is in prep.

Internet Fora – http://fugleognatur.dk/; Facebook group “Bier i felten”.

How many species are DNA barcoded – ca. 100

Number of experts – < 10

Meetings / Organisations – NA

Estonia

General quality of taxonomic knowledge – good

Checklist – no complete one: https://elurikkus.ee/lists/speciesListItem/list/drt5460362684?lang=en

Field Guide – none

Online ID tools – only to bumble bees: https://pmk.agri.ee/sites/default/files/uploads/sites/2/2017/01/Estonian-bumblebees.pdf

Atlas – none

Online atlas or recording scheme – https://elurikkus.ee/en

Handbook or ID keys – only to bumble bees: http://www.looduskalender.ee/suuredpildid/Kimalaste-varvikoodid.pdf?fbclid=I-wAR0CbvHjSY7nCyn5ncBaWJpSajIR2OszOkCj-Na1yC0GSJgU1EnRrqX9daM

National Red List – Lilleleht (2001): http://www.zbi.ee/punane/muu/saateks_e.html;

http://vana.elurikkus.ut.ee/prmt.php?lang=eng; a new Red List is available here: https://infoleht.keskkonnainfo.ee/default.aspx-?id=-598760291&state=3

Internet Fora – Facebook Group „Meie kimalased ja erakmesilased“

How many species are DNA barcoded – NA

Number of experts – 11

Meetings / Organisations – Bumble bee monitoring group by Estonian University of life Sciences

Finland

General quality of taxonomic knowledge – good

Checklist – Paukkunen et al. (2019) https://laji.fi/en/theme/checklist

Field Guide - Söderman & Leinonen (2003); Parkkinen et al. (2018) to bumble bees

Online ID tools – Swedish website covers Finnish fauna: https://artfakta.se/artbestamning/taxon/apiformes-2002991-fullbildade-bin/artnyckel

Atlas - Söderman & Leinonen (2003); Parkkinen et al. (2018)

Online atlas or recording scheme – https://laji.fi/; https://www.syke.fi/fi-FI/Tutkimus__kehittaminen/Tutkimus_ja_kehittamishankkeet/Hankkeet/Suomen_polyttajahyonteiskantojen_tila_seuranta_ja_hyonteispolytyksen_taloudellinen_merkitys_maataloudelle/Suomen_polyttajahyonteiskantojen_tila_se(49617)

Handbook or ID keys - Söderman & Leinonen (2003); Parkkinen et al. (2018) to bumble bees; additionally, there are several old papers with identification keys for Finnish species (e.g. Niemelä 1936, 1947, 1949, Elfving 1951, Pekkarinen & Teräs 1977).

National Red List – Paukkunen et al. (2019). https://punainenkirja.laji.fi/en

Internet Fora – https://foorumi.laji.fi/

How many species are DNA barcoded – 152 (out of 234)

Number of experts – ca. 5

Meetings / Organisations – The Finnish Expert Group on Hymenoptera has meetings three times per year (http://pistiaistyoryhma.myspecies.info/). Bees are sometimes also discussed in the meetings of the Finnish Entomological Society (Societas Entomologica Fennica, http://www.suomenhyonteistieteellinenseura.org/) and the Entomological Society of Helsinki (Societas Entomologica Helsingforsiensis, https://entomologiska.wordpress.com/).

France

General quality of taxonomic knowledge – medium

Checklist – https://inpn.mnhn.fr/telechargement/referentielEspece/taxref/12.0/menu

Field Guide – none

Online ID tools – in prep.

Atlas – none

Online atlas or recording scheme – http://www.atlashymenoptera.net/

Handbook or ID keys – Berland (1995) / Fauna Helvetica

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – none

Meetings / Organisations – NA

Germany

General quality of taxonomic knowledge – very good

Checklist – Scheuchl & Schwenninger (2015)

Field Guide – none

Online ID tools – none

Atlas – for some federal states

Online atlas or recording scheme – http://www.wildbienen-kataster.de/

Handbook or ID keys – Scheuchl & Willner (2016); Westrich (2019)

National Red List – Westrich et al. (2011)

Internet Fora – several

How many species are DNA barcoded – all species

Number of experts – 10–15

Meetings / Organisations – Hymenopterists' meeting in Stuttgart (biannually)

Greece

General quality of taxonomic knowledge – medium

Checklist – Petanidou (in prep.)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – planned

National Red List – unpublished

Internet Fora – some international listservs: International Commission for Plant-Pollinator Relations (ICPBR@LISTSERV.UOGUELPH.CA), Pollination and Palynology List (POLPAL-L@LISTSERV.UOGUELPH.CA)

How many species are DNA barcoded – < 100

Number of experts – 1 + some PhD students

Meetings / Organisations – NA

Hungary

General quality of taxonomic knowledge – medium

Checklist - Józan (2011)

Field Guide – none

Online ID tools – none

Atlas – Bumble bees: Sárospataki et al. (2003)

Online atlas or recording scheme – none

Handbook or ID keys -Móczár (1957, 1958); keys to Apidae, Megachilidae, Halictidae, Melittitidae, Collettidae in Hungarian (only Andrenidae missing)

National Red List – for bumble bees in Sárospataki et al. (2005)

Internet Fora – https://www.facebook.com/groups/613454568726835/

How many species are DNA barcoded – NA

Number of experts – 6–8

Meetings / Organisations – NA

Ireland

General quality of taxonomic knowledge – very good

Checklist – Else et al. (2016)

Field Guide – Falk (2015)

Online ID tools – https://pollinators.ie/record-pollinators/id-guides/

Atlas – Else & Edwards (2018)

Online atlas or recording scheme – https://maps.biodiversityireland.ie/Dataset/5; https://pollinators.ie/record-pollinators/bees/national-database/

Handbook or ID keys – Else & Edwards (2018)

National Red List – Fitzpatrick et al. (2006)

Internet Fora – https://www.facebook.com/groups/insectsinvertebratesire/

How many species are DNA barcoded – ca. 90%

Number of experts – ca. 10

Meetings / Organisations – The main relevant organisation is the All-Ireland Pollinator Plan, www.pollinators.ie (yearly meetings); Irish Pollinator Research Network (academic research network that meets once per year)

Italy

General quality of taxonomic knowledge – medium

Checklist – Pagliano (1995); Comba (2019); a new one is in prep. (M. Quaranta, M. Cornalba)

Field Guide – Quaranta (2019), key to genera

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – Quaranta et al. (in press)

Internet Fora – Facebook page: Beewatching; http://www.apiselvatiche.it; http://www.beewatching.it;

How many species are DNA barcoded – A barcoding project is currently being started

Number of experts – 5–10

Meetings / Organisations – meetings every 3 months; CREA is the leading research organisation; several universities carry out projects. Crea-AA organizes courses several times a year on wild bee taxonomy, melissopalynology, sensory analysis of honey, beekeeping expert and bee pathology.

Latvia

General quality of taxonomic knowledge – medium

Checklist – http://leb.daba.lv/Apocryta.htm

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – https://dabasdati.lv/en

Handbook or ID keys – none

National Red List – A national Red Data Book was published in 1998

Internet Fora – https://dabasdati.lv/en

How many species are DNA barcoded – NA

Number of experts – 3–4

Meetings / Organisations – Entomological Society of Latvia

Lithuania

General quality of taxonomic knowledge – medium

Checklist – Monsevičius (1995)

Field Guide – Tamutis et al. (2010) on bumble bees

Online ID tools – none

Atlas – Monsevičius (1995)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – Rašomavičius (2007)

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – one

Meetings / Organisations – Annual conference of Lithuanian entomological society

Luxembourg

General quality of taxonomic knowledge – good

Checklist – Rasmont (1995)

Field Guide – none

Online ID tools – none

Atlas – in prep.

Online atlas or recording scheme – mdata.mnhn.lu

Handbook or ID keys – European guides

National Red List – none

Internet Fora – none

How many species are DNA barcoded – all

Number of experts – 2–3

Meetings / Organisations – NA

Malta

General quality of taxonomic knowledge – medium

Checklist – Balzan et al. (2016)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – With the eNGO Friends of the Earth Malta a mobile app to record the most common 10 bee species has been developed

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – 44

Number of experts – two

Meetings / Organisations – NA

The Netherlands

General quality of taxonomic knowledge – very good

Checklist – https://www.nederlandsesoorten.nl/linnaeus_ng/app/views/species/nsr_taxon.php?id=161639

Field Guide – Falk & Lewington (2017); van Breugel (2019); Smit et al. (2018) for bumble bees:

Online ID tools – https://determineren.nederlandsesoorten.nl/linnaeus_ng/app/views/matrixkey/index.php?p=tuinbijen

Atlas – https://www.bestuivers.nl/publicaties/de-nederlandse-bijen

Online atlas or recording scheme – www.waarneming.nl; a new bumble bee recording scheme has been started

Handbook or ID keys – Nieuwenhuijsen & Peeters (2016); Peeters et al. (2012): key to genera only

National Red List – Reemer et al. (2018)

Internet Fora – https://forum.waarneming.nl/smf/index.php?board=215.0; Facebook group "Solitaire bijen & hommels"

How many species are DNA barcoded – ca. 200

Number of experts – 15–30

Meetings / Organisations – "Sectie Hymenoptera" of the Dutch entomological society (NEV) organizes several field meetings and symposia every year. EIS Kenniscuntrum Insecten also organizes meetings sometimes. Nederland Zoemt": www.nederlandzoemt.nl (project for raising bee awareness among the Dutch citizens)

Poland

General quality of taxonomic knowledge – good

Checklist – Banaszak (2000)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – Głowaciński & Nowacki (2009)

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – 5–10

Meetings / Organisations – NA

Portugal

General quality of taxonomic knowledge – medium

Checklist – Baldock et al. (2018)

Field Guide – none

Online ID tools – none

Atlas – Only the provincial records in Baldock et al. (2018)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – none

Meetings / Organisations – NA

Romania

General quality of taxonomic knowledge – medium

Checklist – Tomozei (2010): Andreiinae; Ban-Calefariu (2009): Megachilidae; Tomozei (2008): Colletidae; Ban (2006): Anthophoridae

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – Ban-Calefariu (2016): Megachilidae and Anthophoridae

National Red List – none

Internet Fora – http://www.beesofromania.ro/home-1

How many species are DNA barcoded – NA

Number of experts – 1–2

Meetings / Organisations – NA

Slovakia

General quality of taxonomic knowledge – good

Checklist – Bogusch et al. (2007)

Field Guide – Pavelka & Smetana (2000)

Online ID tools – none

Atlas – http://www.academia.cz/blanokridli-ceske-republiky-i-zahadlovi-ii-dotisk--macek-jan--academia--2017

Online atlas or recording scheme – none

Handbook or ID keys – Pavelka & Smetana (2000)

National Red List – Belakova (1996)

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – ca. 5

Meetings / Organisations – regular meetings – Blanokridli v Ceskych zemich a na Slovensku. (Hymenoptera in the Czech lands and Slovakia) http://hymenoptera.wz.cz/

Slovenia

General quality of taxonomic knowledge – medium

Checklist – http://www2.pms-lj.si/andrej/apoidea.htm

Field Guide – Gogala (2014)

Online ID tools – none

Atlas – Gogala (2014), partial

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – a few on bumble bees, 1 student

Meetings / Organisations – NA

Spain

General quality of taxonomic knowledge – medium

Checklist - Ortiz-Sánchez (2011)

Field Guide - Aguado Martín et al. (2017)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – partially in AtlasHymenoptera

Handbook or ID keys - partly in Ortiz-Sánchez & Gellego (2004)

National Red List - Verdú & Galante (2006)

Internet Fora – https://www.biodiversidadvirtual.org/; http://www.anthos.es/

How many species are DNA barcoded – NA

Number of experts – ca. 5

Meetings / Organisations – ECOFLOR meets yearly, but its focus is on ecology and evolution of flower - flower visitors interactions.

Sweden

General quality of taxonomic knowledge – very good

Checklist – www.dyntaxa.se

Field Guide - only for bumble bees: Cederberg & Mossberg (2012), Söderström (2013)

Online ID tools – https://artfakta.se/artbestamning/taxon/apiformes-2002991-fullbildade-bin/artnyckel; https://artfakta.se/artbestamning/artnycklar (not all to species level)

Atlas – none

Online atlas or recording scheme – https://artfakta.se/artbestamning/taxon/apoidea-6001952; Bumble bees are being recorded within the National Inventory of the Landscape in Sweden (NILS): https://www.slu.se/en/Collaborative-Centres-and-Projects/nils/

Handbook or ID keys – none

National Red List – SLU Artdatabanken (2020). Red Listed species in Sweden 2020. SLU, Uppsala

Internet Fora – Facebook groups: "Insekter i Sverige", "Vilken insekt?"

How many species are DNA barcoded – NA

Number of experts – 5–6

Meetings / Organisations – There is a red list committee for Hymenopterans including five species experts. They are coordinated from the Species Information Center (https://www.artdatabanken.se/), and have regular meetings. There is also a Swedish Entomological Society: http://www.sef.nu/om-sef/information_in_english/.

https://www.naturskyddsforeningen.se/raddabina/ is a project initiated by a non-governmental organisation in Sweden called the Swedish Society for Nature Conservation (SSNC) to involve the public in doing different actions to save the bees and also report the effects of their actions.

UK

General quality of taxonomic knowledge – very good

Checklist – Else & Edwards (2018); https://www.bwars.com/content/checklist-british-and-irish-aculeate-hymenoptera-0

Field Guide – Falk & Lewington (2015); Else & Edwards (2018)

Online ID tools – none

Atlas – Provisional Atlas of the Aculeate Hymenoptera of Britain and Ireland, Parts 1–10 BWARS/BRC-CEH (1995–2018). Updated maps also available at https://www.bwars.com/content/bwars-maps-and-species-concepts

Online atlas or recording scheme – https://www.bwars.com/content/bwars-maps-and-species-concepts

Handbook or ID keys – Else & Edwards (2018)

National Red List – Shirt (1987); Falk (1991), a new one is in prep.

Internet Fora – The most widely used are those managed by BWARS on Facebook. BWARS runs its own FB pages as a means of disseminating information and also runs UK Bees Wasps & Ants FB discussion pages which deal with identification. Currently over 9,000 members

How many species are DNA barcoded – 277

Number of experts – ca. 100

Meetings / Organisations – BWARS has an annual weekend Reunion (in Autumn) and publishes a twice yearly newsletter. The Bumblebee Conservation Trust (https://www.bumblebeeconservation.org) publishes "Buzzword" several times a year and runs training workshops in Bumble bee identification and monitoring. BBCT holds an annual members' day each Autumn.

EU-wide tools

Rasmont P, Iserbyt I 2010–2014. Atlas of the European Bees: genus Bombus. 3d Edition. STEP Project, Atlas Hymenoptera, Mons, Gembloux. http://www.atlashymenoptera.net

Smit 2018 Key to Nomada: https://www.nhbs.com/identification-key-to-the-european-species-of-the-bee-genus-nomada-scopoli-1770-hymenoptera-apidae-including-23-new-species-book

Nieto et al. (2014). European Red List

European Atlas project: http://www.atlashymenoptera.net

Appendix 7.2. Butterfly expertise (answers by country)

Austria

General quality of taxonomic knowledge – very good

Checklist – Huemer (2013)

Field Guide – Stettmer et al. (2007), but with errors

Online ID tools – none

Atlas – Reich (1992), outdated

Online atlas or recording scheme – none

Handbook or ID keys – Stettmer et al. (2007), but with errors

National Red List - Höttinger & Pennerstorfer (2005)

Monitoring – being established in 2020, ABLE support

Internet Fora – www.schmetterlingsapp.at

How many species are DNA barcoded – NA

Number of experts – ca. 20

Meetings / Organisations – none

Belgium

General quality of taxonomic knowledge – very good

Checklist – Fichefet et al. (2008) for Wallonia; Wynhoff et al. (2014)

Field Guide – Wynhoff et al. (2014)

Online ID tools – ObsIdentify, http://biodiversite.wallonie.be/fr/determinations.html?IDC=798

Atlas – Maes et al. (2013); Fichefet et al. (2008)

Online atlas or recording scheme – https://waarnemingen.be/; http://biodiversite.wallonie.be/fr/papillons.html?IDC=797; Lycaena Working Group: http://biodiversite.wallonie.be/fr/groupe-de-travail.html?IDC=3339

Handbook or ID keys – Wynhoff et al. (2014)

National Red List – Maes et al. (2012) for Flanders / Fichefet et al. (2008) for Wallonia

Monitoring – Flanders; since 1991; ~20 sites

Internet Fora – https://www.facebook.com/Vlinderwerkgroep-van-Natuurpunt-356745054440335/ Forum Lycaena (Lycaena@yahoogroups.com)

How many species are DNA barcoded – NA

Number of experts – ca. 50 (+ 500 amateurs)

Meetings / Organisations – the Flemish Butterfly Study Group organises a one-day symposium every two years; Lycaena Working Group : http://biodiversite.wallonie.be/fr/groupe-de-travail.html?IDC=3339

Bulgaria

General quality of taxonomic knowledge – very good

Checklist – http://www.butterfliesofbulgaria.com/main%20menu.html

Field Guide – only for Vitosha Mts (Beshkov)

Online ID tools – http://www.butterfliesofbulgaria.com/main%20menu.html

Atlas – Abadjiev (2001)

Online atlas or recording scheme – none

Handbook or ID keys – Abadjiev (1993a,b, 1995)

National Red List – very incomplete

Monitoring – none

Internet Fora – none

How many species are DNA barcoded – ca. 50

Number of experts – ca. 5

Meetings / Organisations – NA

Croatia

General quality of taxonomic knowledge – good

Checklist – Šašić & Mihoci (2011)

Field Guide – none

Online ID tools – none

Atlas – Jakšić (1988)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – Šašić et al. (2015)

Monitoring – in prep.

Internet Fora – none

How many species are DNA barcoded – ca. 125

Number of experts – ca. 5

Meetings / Organisations – NA

Cyprus

General quality of taxonomic knowledge – good

Checklist – John & Skule (2016)

Field Guide – Makris (2003), a new one in prep.

Online ID tools – http://www.cyprusbutterflies.co.uk/

Atlas – Makris (2003)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Monitoring – being established in 2020, ABLE support

Internet Fora – http://www.cyprusbutterflies.co.uk/; Cyprus Butterfly Study Group on Facebook

How many species are DNA barcoded – ca. 10

Number of experts – > 4

Meetings / Organisations – Cyprus Butterfly Study Group (formed in 2012)

Czech Republic

General quality of taxonomic knowledge – very good

Checklist – https://portal.nature.cz/redlist/v_nd_taxon_category.php?X=X

Field Guide – many

Online ID tools – https://play.google.com/store/apps/details?id=cz.hotarekv.atlas&hl=cs; http://www.lepidoptera.cz/klic/

Atlas – http://www.lepidoptera.cz/publikace/pokus-publikaceAtlas?

Online atlas or recording scheme – https://portal.nature.cz/publik_syst/nd_nalez-public.php?idTaxon=31620

Handbook or ID keys – several

National Red List – http://www.ochranaprirody.cz/res/archive/372/058766.pdf?seek=1509546816

Monitoring – none

Internet Fora – Facebook groups Biodiverzita nad zlato

How many species are DNA barcoded – ca. 40

Number of experts – 80 experts, 150 amateurs

Meetings / Organisations – Česká společnost entomologická (meetings 2x per year) https://www.entospol.cz/ Sppolečnost pro ochranu motýlů / SOM (meetings 2x per year) http://www.lepidoptera-som.cz/en_home.html

Denmark

General quality of taxonomic knowledge – very good

Checklist – https://www.fugleognatur.dk/artsliste.asp?PageNo=2&id=7&sort=1

Field Guide – several on www.fugleognatur.dk

Online ID tools – www.fugleognatur.dk; www.danske-natur.dk; http://lepidoptera.dk/guide/index.php

Atlas – https://www.sommerfugleatlas.dk/

Online atlas or recording scheme – https://www.sommerfugleatlas.dk/; Bugbase on Lepidoptera.dk

Handbook or ID keys – Stoltze (1998)

National Red List – https://naturstyrelsen.dk/naturoplevelser/regler-i-naturen/dagsommerfugle/

Monitoring – none

Internet Fora – www.lepidoptera.dk; www.danske-natur.dk; www.fugleognatur.dk; https://aarhus-entomologklub.dk; http://www.nlk.dkx.dk/

How many species are DNA barcoded – NA

Number of experts – ca. 100

Meetings / Organisations – Lepidopterologisk Forening in Copenhagen

Estonia

General quality of taxonomic knowledge – very good

Checklist - Jürivete & Õunap (2008); Aarvik et al. (2017); Maes et al. (2019)

Field Guide - Õunap & Tartes (2014)

Online ID tools – none

Atlas – Tiitsaar et al. (2019)

Online atlas or recording scheme – https://lva.keskkonnainfo.ee/; https://elurikkus.ee/

Handbook or ID keys - Õunap & Tartes (2014)

National Red List – https://infoleht.keskkonnainfo.ee/default.aspx?id=-598760291&state=3

Monitoring – Since 2004, ~10 sites

Internet Fora – two Facebook groups devoted to Estonian butterflies and moths

How many species are DNA barcoded – NA

Number of experts – ca. 15

Meetings / Organisations – Estonian Lepidopterologists' Society holds its meetings twice per year.

Finland

General quality of taxonomic knowledge – very good

Checklist – Aarvik et al. (2017)

Field Guide – Haahtela et al. (2006)

Online ID tools – none

Atlas - Huldén et al. (2000); Saarinen & Jantunen J (2013)

Online atlas or recording scheme – https://laji.fi/theme/nafi/instructions

Handbook or ID keys – Marttila et la. (2000)

National Red List – Kaitila JP et al. (2010)

Monitoring – Since 1999, ~100 sites

Internet Fora –Facebook groups

How many species are DNA barcoded – NA

Number of experts – 100–200

Meetings / Organisations – Finnish Lepidopterological Society: http://www.perhostutkijainseura.fi/

France

General quality of taxonomic knowledge – good

Checklist – https://inpn.mnhn.fr/espece/indicateur/FR/ES/7/FM/OR/Lepidoptera

Field Guide – many (e.g. Lafranchis 2009, 2016; Tolman & Lewington 2015)

Online ID tools – none

Atlas – several regional atlases, no national one

Online atlas or recording scheme – https://inpn.mnhn.fr/accueil/index; http://www.vigienature.fr/fr/suivi-temporel-des-rhopaloceres-de-france-sterf; http://www.vigienature.fr/fr/operation-papillons; http://www.vigienature.fr/fr/propage

Handbook or ID keys – none

National Red List – https://uicn.fr/liste-rouge-papillons-de-jour/

Monitoring – Since 2006, ~600 sites

Internet Fora – several, for instance https://insecte.org/

How many species are DNA barcoded – NA

Number of experts – 30–50

Meetings / Organisations – Several regional meetings

Germany

General quality of taxonomic knowledge – very good

Checklist – Settele et al. (2015)

Field Guide – Settele et al. (2015)

Online ID tools – https://www.ufz.de/tagfalter-monitoring/index.php?de=41776

Atlas – Reinhardt et al. (in press)

Online atlas or recording scheme – https://www.ufz.de/tagfalter-atlas/

Handbook or ID keys – Settele et al. (2015)

National Red List – Reinhardt et al. (2011)

Monitoring – Since 2005, ~460 sites

Internet Fora – http://www.lepiforum.de/

How many species are DNA barcoded – all

Number of experts – ca. 300

Meetings / Organisations – yearly meetings: https://www.ufz.de/tagfalter-monitoring/

Greece

General quality of taxonomic knowledge – very good

Checklist – none

Field Guide – Pamperis (2009)

Online ID tools – http://www.pamperis.gr/btf_site/

Atlas – http://www.pamperis.gr/THE_BUTTERFLIES_OF_GREECE/English.html

Online atlas or recording scheme – http://www.pamperis.gr/btf_site/

Handbook or ID keys – Pamperis (2009)

National Red List – Maes et al. (2019)

Monitoring – under development

Internet Fora – http://portal.cybertaxonomy.org/flora-greece/intro

How many species are DNA barcoded – NA

Number of experts – 20–30

Meetings / Organisations – NA

Hungary

General quality of taxonomic knowledge – good

Checklist - Bálint (2016); Pastorális et al. (2016)

Field Guide – Gergely P et al. (2017)

Online ID tools – http://jasius.hu/lepidopterology/; www.macrolepidoptera.hu

Atlas - Bálint et al. (2006)

Online atlas or recording scheme – There is one recording scheme run by an NGO (data not public), and another one by the national protection authorities, focussed on protected species

Handbook or ID keys – several

National Red List – Varga (1989)

Monitoring – Since 2004, ~20 sites

Internet Fora – Magyarországi Nappali Lepke Térkép-Butterfly Conservation Hungary

webpage: http://lepketerkep.termeszet.org/

How many species are DNA barcoded – NA

Number of experts – ca. 12

Meetings / Organisations –Magyar Rovartani Tártsaság (Hungarian Entomological Society) has regular monthly meetings. The Szalkay József Magyar Lepkészeti Egyesület (Hungarian Lepidopterological Club of József Szalkay) organizes annual meetings; Országos Lepkész Találkozó (National Lepidopterological Meetings) annual meetings; website: lepkeszet.hu; www.facebook.com/lepimonitoring.

Ireland

General quality of taxonomic knowledge – good

Checklist – Bond et al. (2006)

Field Guide – Dublin Naturalist Field Club (2010); National Biodiversity Data Centre (2017)

Online ID tools – http://www.biodiversityireland.ie/record-biodiversity/butterfly-monitoring-scheme/about/how-to-identify-butterflies/

Atlas – Asher et al. (2001); Nash et al. (2010)

Online atlas or recording scheme – http://www.biodiversityireland.ie/record-biodiversity/butterflyatlas/

Handbook or ID keys – Harding (2008)

National Red List – https://www.npws.ie/sites/default/files/publications/pdf/RL_2010_Butterflies.pdf

Monitoring – Since 2007, ~150+ sites

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – ca. 10

Meetings / Organisations – https://butterflyconservation.ie/wp/; http://www.biodiversityireland.ie/record-biodiversity/butterfly-monitoring-scheme/

Italy

General quality of taxonomic knowledge – good

Checklist – Balletto et al. (2014)

Field Guide – None with all Italian species, two for the Italian Alps or smaller regions

Online ID tools – ABLE has created online field guides for four Italian regions: https://butterfly-monitoring.net/bms-materials

Atlas – Balletto et al. (2007); http://www.faunaitalia.it/

Online atlas or recording scheme – https://butterfly-monitoring.net/it

Handbook or ID keys – none

National Red List – Bonelli et al. (2018)

Monitoring – Since 2018, 45 sites

Internet Fora – none

How many species are DNA barcoded – > 200 (but probably much higher number has been barcoded but not published, yet)

Number of experts – ca. 10

Meetings / Organisations – yearly: https://barcoding.wixsite.com/italianbutterflies/eventi

Latvia

General quality of taxonomic knowledge – very good

Checklist – Savenkovs & Šulcs (2010); Aarvik et al. (2017) http://www.entomologi.no/journals/nje/Suppl/Aarvik_et_al_2017_Nordic-Baltic_Checklist_of_Lepidiptera.pdf

Field Guide – none

Online ID tools – https://dabasdati.lv/site/img/pub/1/2/46/1336567356.pdf; https://dabasdati.lv/site/img/pub/1/2/145/1357548334.pdf; https://dabasdati.lv/site/img/pub/1/2/147/1358159007.pdf

Atlas – none

Online atlas or recording scheme – Dabasdati.lv; ej.uz/tv5x5

Handbook or ID keys – none

National Red List – Spuris Z. (1998)

Monitoring – 30 sites (there are two butterfly monitoring schemes in Latvia.)

Internet Fora – none

How many species are DNA barcoded – ca. 30

Number of experts – ca. 10 (+ 40 amateurs)

Meetings / Organisations – Entomological Society of Latvia

Lithuania

General quality of taxonomic knowledge – good

Checklist – Ivinskis (2004) http://www.entomologi.no/journals/nje/Suppl/Aarvik_et_al_2017_Nordic-Baltic_Checklist_of_Lepidiptera.pdf

Field Guide – Ivinskis & Augustauskas (2004)

Online ID tools – none

Atlas – Kazlauskas (1984), Ivinskis & Augustauskas (2004)

Online atlas or recording scheme – Private database by Giedrius Švitra LepiBase

Handbook or ID keys – none

National Red List – https://g4.dcdn.lt/gr/rk/1_ivadas.pdf, a new version is in prep.

Monitoring – none

Internet Fora –Facebook site of Lithuanian Entomological Society, closed e-mail forum of butterfly experts

How many species are DNA barcoded – NA

Number of experts – ca. 10

Meetings / Organisations – Lithuanian Entomological Society (meetings 2x per year)

Luxembourg

General quality of taxonomic knowledge – very good

Checklist – Mestdagh et al. (in press)

Field Guide – several from adjacent countries

Online ID tools – none

Atlas – Mestdagh et al. (in press)

Online atlas or recording scheme – mdata.mnhn.lu

Handbook or ID keys – none

National Red List – Mestdagh et al. (in press)

Monitoring – Since 2010, ~50+ sites

Internet Fora – pimpampel@googlegroups.com

How many species are DNA barcoded – NA

Number of experts – ca. 15

Meetings / Organisations – NA

Malta

General quality of taxonomic knowledge – very good

Checklist – Cassar (2018)

Field Guide – Cassar (in prep.)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – European ones

National Red List – An old red list exists (1989), but a new one is in prep.

Monitoring – none

Internet Fora – Facebook group

How many species are DNA barcoded – NA

Number of experts – ca. 6

Meetings / Organisations – There is a local entomological society, which publishes a Bulletin

The Netherlands

General quality of taxonomic knowledge – very good

Checklist – https://www.vlinderstichting.nl/vlinders/alles-over-vlinders/naamgeving-en-systematiek/naamlijst-nederlandse-vlinders/

Field Guide – Wynhoff (2009)

Online ID tools – https://www.vlinderstichting.nl/vlinders/vlinders-herkennen/; ObsIdentify

Atlas – Bos & Bosveld (2006)

Online atlas or recording scheme – https://waarneming.nl/; www.telmee.nl https://www.vlinderstichting.nl/vlinders/overzicht-vlinders/details-vlinder/spiegeldikkopje;

Handbook or ID keys – none

National Red List – van Swaay et al. (2019): https://assets.vlinderstichting.nl/docs/ea504174-725d-4b69-9401-ba364f4ed3de.pdf

Monitoring – Since 1990, ~800 sites

Internet Fora – forum.waarneming.nl

How many species are DNA barcoded – NA

Number of experts – ca. 1000 volunteers involved in monitoring, a few thousand submit data in waarneming.nl and telmee.nl

Meetings / Organisations – annual butterfly day with 650 people attending

Poland

General quality of taxonomic knowledge – good

Checklist – Buszko & Nowacki (2017)

Field Guide – Sielezniew & Dziekańska (2010)

Online ID tools – none

Atlas – Buszko (1997)

Online atlas or recording scheme – http://lepidoptera.ksib.pl/index.php?id=mp&l=en

Handbook or ID keys – Buszko & Masłowski (2015); Sielezniew & Dziekańska (2010)

National Red List – Buszko et al. (2002), a new one is planned

Monitoring – under development

Internet Fora – https://www.entomo.pl/forum/

How many species are DNA barcoded – ca. 10

Number of experts – 5–10

Meetings / Organisations – Annual meetings of Polish Entomological Society (lepidopterological section)

Portugal

General quality of taxonomic knowledge – very good

Checklist – http://bc-europe.eu/upload/RDB_Butterflies_1999.pdf

Field Guide – Maravalhas (2003)

Online ID tools – none

Atlas – http://sea-entomologia.org/PDF/MSEA11Lepidopteradiurnos.pdf

Online atlas or recording scheme – http://www.tagis.pt/censos-borboletas-de-portugal.html#

Handbook or ID keys – none

National Red List – in prep.

Monitoring – Since 2019, ~5 sites

Internet Fora – https://www.facebook.com/groups/LepidopteraPortugal/

How many species are DNA barcoded – all

Number of experts – ca. 20

Meetings / Organisations – A first meeting for 2020 in prep.

Romania

General quality of taxonomic knowledge – good

Checklist - Rákosy et al. (2013): http://lepidoptera.ro/files/catalogul_lepidopterelor_din_romania.pdf; new checklist in prep.

Field Guide – none

Online ID tools – none

Atlas - Rákosy et al. (2003)

Online atlas or recording scheme – none

Handbook or ID keys - Rákosy (2013)

National Red List - Rákosy et al. (2013), a new one in prep.

Monitoring – https://sites.google.com/site/monitorizareafluturilor/home

Internet Fora – none

How many species are DNA barcoded – ca. 180 species

Number of experts – 20–30

Meetings / Organisations – One yearly meeting of the Lepidopterologocal Society of Romania with 20 participants

Slovakia

General quality of taxonomic knowledge – medium

Checklist – http://www.ffs.sk/pdf/FFS-18-15-Pastoralis-et-al-2013.pdf

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – https://lepidoptera.sk/mapovanie-motylov-slovenska

Handbook or ID keys – Macek (2015); Slamka (2004)

National Red List – http://ibot.sav.sk/lichens/docs/Pisut_Guttova_Lackovicova_Lisicka_2001.pdf

Monitoring – none

Internet Fora – in prep.

How many species are DNA barcoded – NA

Number of experts – < 10

Meetings / Organisations – each year (with Czech colleagues)

Slovenia

General quality of taxonomic knowledge – very good

Checklist – Verovnik (2019)

Field Guide – Polak (2009), not covering the complete country

Online ID tools – http://dbiodbs.units.it/carso/chiavi_pub21?sc=654

Atlas – Verovnik et al. (2012)

Online atlas or recording scheme – Recording scheme present, but not yet online.

Handbook or ID keys – none

National Red List – https://www.uradni-list.si/files/RS_-2002-082-04055-OB~P016-0000.PDF (outdated)

Monitoring – Since 2017

Internet Fora – mailing list of the DPOMS

How many species are DNA barcoded – NA

Number of experts – ca. 10

Meetings / Organisations – DPOMS (Society for Conservation and Study of Lepidoptera of Slovenia)

Spain

General quality of taxonomic knowledge – very good

Checklist - García-Barros et al. (2013)

Field Guide – Objectiu Natura (2012); many regional field guides

Online ID tools – Biodiversidad Virtual

Atlas - García-Barros et al. (2004) http://sea-entomologia.org/PDF/MSEA11Lepidopteradiurnos.pdf

Online atlas or recording scheme - CATBMS in Catalonia, Zerynthia for the Basque Country and Navarra, BMS España for the rest of Spain, including the Canary Islands, uBMS records urban butterflies in parks of Madrid and Barcelona; Biodiversidad Virtual.

Handbook or ID keys - García-Barros et al. (2013)

National Red List - Viedma et al. (1985); Verdú & Galante (2006); Verdú et al. (2009, 2011)

Monitoring – Catalonia: since 1994, ~170 sites; Basque: since 2010; Spain (elsewhere): since 2014

Internet Fora - Facebook identification forum “Mariposas y Polillas”; Facebook group of the BMS España recording scheme; Websites of Zerynthia and CATBMS; Biodiversidad Virtual

How many species are DNA barcoded – all (Dincă et al. 2015)

Number of experts – ca. 20 + 300 amateurs

Meetings / Organisations – SHILAP publishes the journal Shilap Revista de Lepidopterología; Societat Catalana de Lepidopterología publishes a Bulletin and holds regular meetings.

Sweden

General quality of taxonomic knowledge – good

Checklist – https://www.artportalen.se/Occurrence/TaxonOccurrence/16/3000188; https://artfakta.se/artbestamning/taxon/papilionoidea-2002976; https://www.nrm.se/en/forskningochsamlingar/zoologi/samlingar/katalogerochartlistor/cataloguslepidopterorum.9003426.html; https://www.dyntaxa.se/Taxon/Info/3000188

Field Guide – several

Online ID tools – several: http://www.lepidoptera.se; http://www.vilkenart.se/; https://artfakta.se/artbestamning/taxon/papilionoidea-2002976

Atlas – several: Bengtsson et al. (2016) https://www.bokus.com/bok/9789188506511/nationalnyckeln-fjarilar-dagfjarilar-klotband-hesperiidae-nymphalidae/; https://bit.ly/31OCfeO; https://www.artportalen.se/Occurrence/TaxonOccurrence/16/3000188; https://artfakta.se/artbestamning/taxon/papilionoidea-2002976; https://www.nrm.se/en/forskningochsamlingar/zoologi/samlingar/katalogerochartlistor/cataloguslepidopterorum.9003426.html;

Online atlas or recording scheme – www.dagfjarilar.lu.se

Handbook or ID keys - Gärdenfors et al. (2005)

National Red List – SLU Artdatabanken (2020). Red Listed species in Sweden 2020. SLU, Uppsala

Monitoring – Since 2010, ~100 sites

Internet Fora – several: http://www.dagfjarilar.lu.se/forum; https://www.facebook.com/groups/369088230659/; https://www.facebook.com/groups/122247664456987/

How many species are DNA barcoded – all

Number of experts – ca. 200

Meetings / Organisations – NA

UK

General quality of taxonomic knowledge – very good

Checklist – included in field guides and online: https://butterfly-conservation.org/butterflies/identify-a-butterfly

Field Guide – several (e.g. Tolman & Lewington 2018; Newland et al. 2015)

Online ID tools – https://butterfly-conservation.org/butterflies/identify-a-butterfly

Atlas – regularly updated: https://butterfly-conservation.org/butterflies/the-state-of-britains-butterflies

Online atlas or recording scheme – none

Handbook or ID keys – https://butterfly-conservation.org/butterflies/identify-a-butterfly

National Red List – Fox et al. (2010): https://butterfly-conservation.org/sites/default/files/red-list.pdf

Monitoring – Since 1976, ~2000 sites

Internet Fora – several

How many species are DNA barcoded – all

Number of experts – ~1500 transect recorders, opportunistic recorders

Meetings / Organisations – One yearly meeting for UK, plus national meetings (e.g. Scotland)

EU-wide tools

Wiemers et al. 2018: An updated checklist of the European Butterflies (Lepidoptera, Papilionoidea), ZooKeys 811: 9–45

European Distribution Maps: https://www.ufz.de/european-butterflies/index.php?de=43003

van Swaay et al. 2010: European Red List

ABLE: European Monitoring Network

Appendix 7.3. Hoverfly expertise (answers by country)

Austria

General quality of taxonomic knowledge – medium

Checklist – Heimburg (2018); a new one is in preparation

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – https://austria-forum.org/af/Natur/Fauna/Insekten/Fliegen/10_Syrphidae_-_Schwebfliegen

How many species are DNA barcoded – NA

Number of experts – 3–4

Meetings / Organisations – NA

Belgium

General quality of taxonomic knowledge – very good

Checklist – Van de Meutter (2011)

Field Guide – Bot & Van de Meutter (2019)

Online ID tools – none

Atlas – Bot & Van de Meutter (2019)

Online atlas or recording scheme – waarnemingen.be

Handbook or ID keys – Bot & Van de Meutter (2019)

National Red List – none

Internet Fora – waarnemingen.be / Whatsapp group

How many species are DNA barcoded – see Netherlands

Number of experts – 3–4

Meetings / Organisations – yearly informal meeting with Belgian (mostly Flemish) amateurs

Bulgaria

General quality of taxonomic knowledge – poor

Checklist – Bankowska (1967)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – 1

Meetings / Organisations – NA

Croatia

General quality of taxonomic knowledge – medium

Checklist – none

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none (keys are available in Serbian PhD theses)

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – none (research has been done mainly by Serbian experts)

Meetings / Organisations – NA

Cyprus

General quality of taxonomic knowledge – poor

Checklist – van Eck (in prep)

Field Guide – Makris (in prep)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – ca. 9 species

Number of experts – two

Meetings / Organisations – NA

Czech Republic

General quality of taxonomic knowledge – good

Checklist – Jedlicka et al (2009)

Field Guide – van Veen (2010)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – van Veen (2010)

National Red List - Mazánek & Barták (2005)

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – one

Meetings / Organisations – Meetings of Czech and Slovakian Dipterologists: http://www.fpv.umb.sk/katedry/katedra-biologie-a-ekologie/veda-a-vyskum/konferencie/10-stredoeuropska-dipterologicka-konferencia/

Denmark

General quality of taxonomic knowledge – very good

Checklist – Petersen & Meyer (2001), Torp (1984a,b); Allearter.dk

Field Guide – Torp (1994), van Veen (2010)

Online ID tools – none

Atlas – Torp (1984), Torp (1994)

Online atlas or recording scheme – https://www.svirreflueatlas.dk/; https://www.fugleognatur.dk/

Handbook or ID keys – Torp (1994), Bartsch et al. (2009)

National Red List – http://bios.au.dk/raadgivning/natur/redlistframe/artsgrupper/ (Bygebjerg 2004). The updated version will be published in 2019

Internet Fora – Naturbasen.dk; https://www.fugleognatur.dk/

How many species are DNA barcoded – a framework is currently under construction: https://dnamark.ku.dk/

Number of experts – 3–4 (+ a couple of excellent amateurs)

Meetings / Organisations – none

Estonia

General quality of taxonomic knowledge – poor

Checklist – Kuznetzov (1993); Haarto & Kerppola (2007)

Field Guide – van Veen (2010)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – https://elurikkus.ee/en

Handbook or ID keys – none

National Red List – assessments have been done last year for 220 species (156 DD, 56 LC)

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – one

Meetings / Organisations – NA

Finland

General quality of taxonomic knowledge – very good

Checklist – Haarto & Kerppola (2004/2014)

Field Guide – van Veen (2010)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – Species.fi

Handbook or ID keys – Haarto & Kerppola (2007), Bartsch et al. (2009a,b)

National Red List – https://www.environment.fi/redlist

Internet Fora – Species.fi, https://foorumi.laji.fi/

How many species are DNA barcoded – 256, but new campaign to increase number

Number of experts – ca. 4

Meetings / Organisations – Several Entomological Societies in Finland (Helsinki, Turku, Tampere, Oulu).

France

General quality of taxonomic knowledge – very good

Checklist – https://app.box.com/s/vp1krc9c64uchrcozu0xagjqo01udn0f; https://app.box.com/s/k7l7fr0z6v9vvkj4um8jue9es7nbw9ns

Field Guide – van Veen (2010)

Online ID tools – http://cyrille.dussaix.pagesperso-orange.fr/L.html

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – StN (Syrph the Net) keys are used in France

National Red List – none

Internet Fora – https://www.insecte.org/forum/viewforum.php?f=11, https://fr.groups.yahoo.com/neo/groups/dipterasyrphidae2/conversations/messages / Diptera.info

How many species are DNA barcoded – NA

Number of experts – several

Meetings / Organisations – every 3 years; https://app.box.com/s/fqcxc8e5eiuaukuqh2r8euulwgvky4bd

Germany

General quality of taxonomic knowledge – good

Checklist – Ssymank et al. (2011)

Field Guide – Kormann (1988/2002), incomplete

Online ID tools – https://offene-naturfuehrer.de/web/Schwebfliegen,_Syrphidae_(Diptera)

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – Bastian (1994), Bothe (1996), incomplete; several keys from neighbouring countries can be used for northern Germany (Van Veen 2010, Bot & Van de Meutter 2019), in addition a number of revisions are needed, partially possible with STN (Syrph The Net))

National Red List – Ssymank et al. (2011)

Internet Fora – none

How many species are DNA barcoded – 305 barcoded, 83 not collected, 86 not barcoded yet

Number of experts – 15–20 (3–4 experts with long-term taxonomic knowledge)

Meetings / Organisations – AK-Diptera (includes hoverflies), yearly introductory courses: introduction to biology and determination of hoverflies at the NUA academy (NRW)

Greece

General quality of taxonomic knowledge – very good

Checklist – Likov (unpubl.)

Field Guide – none

Online ID tools – none

Atlas – Vujić et al. (2020)

Online atlas or recording scheme – none

Handbook or ID keys – Vujić et al. (2020)

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – 2–3

Meetings / Organisations – NA

Hungary

General quality of taxonomic knowledge – good

Checklist -Tóth (2011)

Field Guide – none

Online ID tools – none

Atlas - Tóth (2011)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – one

Meetings / Organisations – NA

Ireland

General quality of taxonomic knowledge – very good

Checklist – Speight (2008)

Field Guide – van Veen (2010)

Online ID tools – http://www.biodiversityireland.ie/wordpress/wp-content/uploads/Beginners-guide-to-Irish-hoverflies-July-2015.pdf; https://pollinators.ie/record-pollinators/id-guides/

Atlas – Speight (2008): http://edepositireland.ie/bitstream/handle/2262/71193/IWM36report.pdf?sequence=1&isAllowed=y

Online atlas or recording scheme – https://maps.biodiversityireland.ie/Dataset/159

Handbook or ID keys – https://pollinators.ie/record-pollinators/hoverflies/syrph-the-net/

National Red List – none

Internet Fora – https://www.facebook.com/groups/insectsinvertebratesire/

How many species are DNA barcoded – NA

Number of experts – several

Meetings / Organisations – identification workshops are run in the National Biodiversity Data Centre

Italy

General quality of taxonomic knowledge – medium

Checklist – Minelli et al. (1995), Daccordi & Sommaggio (2002), Burgio et al. (2015)

Field Guide – none

Online ID tools – none

Atlas – Sommaggio (2005)

Online atlas or recording scheme – Corazza & Sommaggio (2012) for Ferrara Province: https://storianaturale.comune.fe.it/564/atlante-on-line-dei-ditteri-sirfidi-del-ferrarese

Handbook or ID keys – Bertollo & Sommaggio (2012); only to genus level

National Red List – Burgio et al. (2015)

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – 3–4

Meetings / Organisations – Each year the Ferrara Museum of Natural History organises a DEST course for Syrphidae identification.

Latvia

General quality of taxonomic knowledge – poor

Checklist – Kuznetzov (1993), Kuznetzov & Kuznetzova (1996), Karpa A (2008), Cakstina (in prep.)

Field Guide – Bartsch et al. (2009a,b)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – www.dabasdati.lv

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – one, plus 2 enthusiasts

Meetings / Organisations – Entomological Society of Latvia

Lithuania

General quality of taxonomic knowledge – good

Checklist – Kuznetzov (1993), Pakalniskis et al. (2006)

Field Guide – none

Online ID tools – none

Atlas – in prep (Lutovinovas pers. comm)

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – https://www.macrogamta.lt/lt

How many species are DNA barcoded – NA

Number of experts – one

Meetings / Organisations – Lithuanian Entomological Society meetings

Luxembourg

General quality of taxonomic knowledge – good

Checklist – Carrieres (2001,2003), van Steenis (2006)

Field Guide – van Veen (2010)

Online ID tools – none

Atlas – none

Online atlas or recording scheme – mdata.mnhn.lu

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – 2–3

Meetings / Organisations – NA

Malta

General quality of taxonomic knowledge – good

Checklist – Ebejer (1995), Ssymank & Ebejer (2009)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – no residents

Meetings / Organisations – NA

The Netherlands

General quality of taxonomic knowledge – very good

Checklist – Beuk (2002): http://www.diptera-info.nl/infusions/checklist/view_family.php?fam_id=110

Field Guide – Bot & Van de Meutter (2019)

Online ID tools – Schulten (2014), https://waarneming.nl/download/fotogids_Syrphidae.pdf

Atlas – Reemer et al. (2009)

Online atlas or recording scheme – waarneming.nl

Handbook or ID keys – van Veen (2010)

National Red List – none

Internet Fora – http://www.tuin-thijs.com/zweefvliegen-engels.htm; https://www.syrphidaeintrees.com/

How many species are DNA barcoded – >220 species

Number of experts – 10–15

Meetings / Organisations – section Diptera of the Entomological society

Poland

General quality of taxonomic knowledge – good

Checklist – http://syrphidae.insects.pl/checklist.php?lang=en

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – strong group of people working with Syrphidae

Meetings / Organisations – regular meetings

Portugal

General quality of taxonomic knowledge – medium

Checklist – van Eck (2011,2016)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – recently started

Internet Fora – facebook group Diptera

How many species are DNA barcoded – "2–4"

Number of experts – 3–4

Meetings / Organisations – NA

Romania

General quality of taxonomic knowledge – good

Checklist – Stanescu (2005)

Field Guide – Bradescu (1991), outdated

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – one

Meetings / Organisations – NA

Slovakia

General quality of taxonomic knowledge – good

Checklist – Jedlicka et al. (2009)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – none

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – 1–2

Meetings / Organisations – NA

Slovenia

General quality of taxonomic knowledge – good

Checklist – de Groot & Govedic (2008), Steenis et al. (2013)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – https://www.inaturalist.org/projects/hoverflies-of-slovenia.

Handbook or ID keys – van Veen (2010)

National Red List – none

Internet Fora – none

How many species are DNA barcoded – NA

Number of experts – < 10

Meetings / Organisaations – NA

Spain

General quality of taxonomic knowledge – good

Checklist - Ricarte & Marcos-García (2017)

Field Guide – none

Online ID tools – none

Atlas – none

Online atlas or recording scheme – none

Handbook or ID keys – A monograph on the Iberian Eristalinae is currently in prep. There are already Iberian keys to species of some genera (e.g. Merodon). StN and other European keys are used.

National Red List – The red list of the Spanish invertebrates includes 3 hoverfly species (https://cibio.ua.es/lrie/lrie.html).

Internet Fora – https://www.biodiversidadvirtual.org/insectarium/

How many species are DNA barcoded – 277 out of 421

Number of experts – 6

Meetings / Organisations – Iberian Congress of Entomology / Spanish Congress of Entomology

Sweden

General quality of taxonomic knowledge – very good

Checklist – Bartsch (1995); https://www.dyntaxa.se

Field Guide – Bartsch et al. (2009a,b)

Online ID tools – https://www.artportalen.se/

Atlas – Bartsch et al. (2009a,b)

Online atlas or recording scheme – none

Handbook or ID keys – Bartsch et al. (2009a,b)

National Red List – SLU Artdatabanken (2020). Red Listed species in Sweden 2020. SLU, Uppsala

Internet Fora – https://www.artportalen.se/

How many species are DNA barcoded – NA

Number of experts – 3–4

Meetings / Organisations – NA

UK

General quality of taxonomic knowledge – very good

Checklist – www.hoverfly.org.uk

Field Guide – Stubbs & Falk (1993), Ball & Morris (2015, 2016)

Online ID tools – Plenty of online ID tools (e.g. Stephen Falk's Flickr site)

Atlas – Ball et al. (2011)

Online atlas or recording scheme – www.nbnatlas.org

Handbook or ID keys – Stubbs & Falk (2002)

National Red List – Falk & Chandler (2005)

Internet Fora – www.hoverfly.org.uk, Hoverfly Facebook page, etc.

How many species are DNA barcoded – NA

Number of experts – 2–3 (+ amateurs)

Meetings / Organisations – Regular meetings of the Dipterists Forum, www.hoverfly.org.uk, etc.

EU-wide tools

van Veen (2010): Guide to NW Europe

Global website on Diptera: https://diptera.info/news.php

Syrph the Net: http://diptera.myspecies.info/content/syrph-net

8 Emerging Technologies and the Opportunities they offer for Future Pollinator Monitoring

In this Chapter, we describe emerging technologies that could potentially contribute to pollinator monitoring. These include: automatic image analysis for species identification (section 8.2); sound recognition (section 8.3); repeated counts models (section 8.4); landscape analysis (section 8.5); DNA barcoding (section 8.6); and DNA metabarcoding (section 8.7).

8.1 Approach to assessing emerging technologies

Predicting how technology will develop, and what future possibilities will arise, is complex. Here we extrapolated from current trends in technological developments as far as possible, but recognise that novel and unforeseen technologies will continue to emerge. We explore how technological innovations could be incorporated into (pollinator) monitoring schemes and specimen processing/identification chains to enhance the availability and quality data generated. We provide estimates of how long we expect it will take before the different technologies can be widely deployed, although substantial uncertainty remains around these estimates.

We did not assess the possibilities of combining some of these emerging technologies, but recognise that synergies between them could make schemes more resource-effective to run and produce better quality data. For example, combining the automatic image analysis and unmanned aerial vehicles could potentially improve the feasibility of remote data collection and accuracy of identifications. Another example is the possibility of combining the passive technique of sound recognition with image recognition based on actively attracting insects, which could substantially improve identification accuracy. Here we do not speculate

Bombus pascuorum/Lavandula L., Maria Luisa Paracchini on these combinations, as it is hard to predict how these technologies will develop, but advocate an active vigil and frequent re-assessment of emerging opportunities.

For each method, we present: a general description of the method, the potential scope where we explain what type of data we expect the method will produce, likely advantages and disadvantages, and an estimate of the costs. We conclude each section with a view on how this method could be developed in the longer term. For each method we provide a technology readiness level (TRL) estimate, as defined for Horizon 2020[1].

8.2 Automatic image analysis for species identification

Description

Recent advances in artificial intelligence (AI) now allow for the automatic identification of objects in images. Algorithms depend on neural networking where a set of algorithms, modelled loosely on the human brain, are designed to recognise patterns based on analysing training examples. The most commonly used technique for object identification is Convolutional Neural Networking (CNN), which generally requires a large training dataset. The quality of the training dataset largely determines the network quality and performance. When combined with automatic camera traps (Steenweg et al., 2017), they potentially offer a valuable tool for monitoring flower visiting pollinators (Steen, 2017; Tran et al., 2018). CNN-based analyses have been developed to identify plants (Lee et al., 2015), fruit (Bargoti & Underwood, 2017; Sa et al., 2016), moths (Ding & Taylor, 2016) and aquatic macroinvertebrates (Riabchenko et al., 2016). The TRL is estimated at level 7, the technology is already in use in an operational environment for a limited set of species.

Potential scope

In theory, a computer can be trained to recognise almost any object, as long as the information can be extracted from the input data, and sufficient training data are provided. More complicated recognitions require more training time and data. These requirements can become huge and can be difficult to collect. For some species groups, it might not be feasible (at this time) to collect the massive dataset required. How well a group can be recognised cannot always be predicted but a computer may be better at detecting certain species groups than a human expert. Initial experiences show that butterflies appear to be more difficult to recognise than moths, even though, ironically, most humans find butterflies easier to identify. This is potentially due to the difference in quality of the training datasets (moth pictures are often more similar, and therefore easier to recognise for a computer). It should be noted that not all species can be recognised using this technique; if the information is not available in an image, automatic recognition will not work.

Current status and remaining development time

The first algorithms to identify species are already being used in Western Europe, for instance by iNaturalist[2] and Naturalis. They collected large datasets and used TensorFlow[3] to train their neural networks. These algorithms perform well, but are not trained to recognise all species. A project led by Naturalis showed that true bugs (heteropterans) and moths are relatively easy to recognise, while butterflies are more difficult, but with sufficient data this latter group too worked reasonably well. Solitary bees and bumble bees proved much more difficult to recognise, and currently cannot reliably be identified. Naturalis has also constructed an automated camera trap for moths. A camera is focused on a yellow strip of plastic, and once an insect lands, it is automatically identified. Similar to pan trapping (section 4.2.4), this technique suffers from the problem that it competes with local flowers for attracting insects, and therefore its detection chance depends on the local landscape. Additionally, as insects are not captured, it is unclear how often a single individual is counted. Traps that do not rely on colour attraction are starting to come to market (e.g. FaunaPhotonics[4]) but are still very much in their test phase. In this case, invisible infrared light is used to automatically detect an insect as it flies by. This allows measurements of the wing beat frequency, colour and wing to body ratio of each insect flying through the sensor's monitoring field. These technologies are still in their infancy and are not yet capable of reliably distinguishing insects even to broad group level, as would be required for the EU-PoMS.

Requirements

This method requires large datasets (preferably several hundred images per species) of validated images, more if multiple forms, phenotypes or angles of the same species are to be recognised. It should also be taken into account that different possible poses can further increase the required training dataset size. Powerful computers or computational clusters are usually required to train the network, however, once trained it no longer requires large processing capacity to be used, and it can be run on a mobile phone.

1 https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
2 https://www.inaturalist.org/
3 https://www.tensorflow.org/
4 https://www.faunaphotonics.com/

Amegilla quadrifasciata, Maurizio Censini

Estimated costs

Large companies, who continuously develop these algorithms, generally make their findings and tools public. We therefore do not expect high development costs. Some taxonomic expertise is required to properly apply these tools. The exact costs are difficult to estimate, as it will largely depend upon the data availability, which differs between species groups and countries. If images were to be manually validated, time would be ~30 seconds/image which equates to €0.05 to €0.49 per image depending on the country (Breeze et al., 2020). A reference collection of ~50 images from multiple angles is required to support identification and machine learning, although this may be higher if species are highly sexually dimorphic, or have multiple independent colour forms (e.g. Lepidoptera). The costs associated with this method mostly involve the collection and preparation of datasets. It should be noted that this data from museum collections cannot be the sole data source, and might not be suitable at all, as these data generally differ from the input we want to recognise.

Advantages

This technique reduces the expertise required to identify specimens, and also potentially allows fieldwork to be done by personnel or volunteers with minimal training. Additionally, these techniques can be used to validate observations automatically, and on a large scale.

Disadvantages

The involvement of volunteers might decrease when classical diagnostics and species determination are no longer required to recognise different species. Currently, there is a large time investment required to learn to recognise all pollinator species, which ensures volunteers are highly involved.

Additionally, these algorithms are currently poorly adapted to new situations, therefore they might not perform well when the insect is presented in a pose that was not included in the training data.

Possible future development

Potentially, this method could develop to the point where insects are identified from video footage. Volunteers could be given a camera, and asked to walk a route. Pollinators are then identified automatically. Additionally, other parameters could be estimated automatically such as their weight and fitness. Availability of an open access, high quality macrophotography collection could also accelerate development of this approach as well as supporting more traditional field Identification by experts and volunteers.

8.3 Sound recognition

Description

In the previous method we described how pictures can be identified by machine-learning algorithms. These algorithms can also be used to analyse sounds; traditionally the development of these algorithms was focussed on interpreting human speech. However, they are increasingly being incorporated in the field of bioacoustics to analyse environmental sounds (Singh & Joshi, 2019) and identify animals such as bats (Mac Aodha et al., 2018), birds (Grill & Schlüter, 2017) and even bumble bee flight buzzing sounds (Gradišek et al., 2017). There is emerging evidence that plants also detect sounds and can change their behaviour accordingly (Gagliano, 2013), by, for example, producing more nectar when pollinators are near (Veits et al., 2019). Projects such as AudioMoth[5] offer open specialised hardware to record sounds continuously on a large range of frequencies (Hill et al., 2019), making large-scale sound recording a cost effective option. The emergence of cheap specialised hardware, combined with increasing availability of processing algorithms, makes this a potentially huge data source with limited biases. The TRL for this technique is TLR level 3; an experimental proof of concept is available.

Potential scope

This can be used as a passive method, i.e. it does not depend upon attracting insects. The performance of active methods (such as pan trapping) can strongly differ between landscape types; in contrast, this passive method is expected to have a relatively small landscape bias. A well-established drawback of passive methods in general, their lower data collection rate, also applies to sound recognition. However, as audio recorders are relatively cheap and can collect data continuously, this drawback is likely to be less problematic than with regular passive methods. Passive methods generally produce a higher data quality (in terms of attraction biases), therefore, this method potentially offers a large dataset of high quality data that can be used in a large-scale monitoring

5 https://www.openacousticdevices.info/

network. It should be noted though, that for many pollinators sound is a by-product, and as there is much size variation within species (e.g. bumble bee queens vs. workers), and size is one of the most important factors for the production of sound, there is no guarantee that identification to species level will be possible. In this case identification to a species cluster/group may only be possible.

Current status and remaining development time

Cheap recorders are already available and the first algorithms to automatically identify sounds are starting to emerge. These algorithms will have to be developed further before they can be widely applied, and are able to distinguish between European pollinator species with sufficient confidence to be used in wide scale monitoring. Even with ongoing developments, it may not be possible to identify every sound to species level. We expect at least 5–10 years of continued development is needed before the algorithms are able to support large-scale applications. However, data collection is already possible.

Requirements

This method has several requirements, a large network of microphones, algorithms and servers to process sound files. These recorders produce data continuously, requiring a large storage capacity for sound files. Eventually microphone systems will develop to the point where they can parse sound files themselves and pass on only the identified species, but at the first stages these sound files should be stored to help train algorithms.

Estimated costs

The costs of a single microphone are estimated at around €50 to 100 per device. Microphones provide point observations and therefore multiple microphones (say 5 to 20) would be needed to cover an area similar to a typical butterfly or bee transect. Additional costs would include developing a validated reference collection and machine learning time to develop these into useable data.

Advantages

This method does not depend on attracting insects; therefore it will have a no colour or floral context bias. As an automated technique, this can potentially provide a huge high quality dataset.

Disadvantages

Insects are not captured, therefore it is possible to record a single individual multiple times. It might not be possible to identify all species based on their sound. This could potentially be addressed by combining it with other automated methods, such as the automated camera traps. Depending on the country, theft and vandalism of equipment might be a problem. Recording sounds risks invasion of human privacy, and regulations could forbid placing these recorders in certain locations.

Possible future development

In the longer term, this method could automatically and instantaneously identify species and pass them on to a central server directly. With a wide network of microphones it could be possible to track insect occurrence and abundance in real time.

8.4 Repeated counts models

Description

Detection changes differ between habitats; detection probability has been studied in butterflies (Isaac et al., 2011), especially by studies comparing multiple methods (Kadlec et al., 2012; Royer et al., 1998), and probabilities were found to differ between habitats. This is a very common problem that affects many different monitoring techniques. A study of the butterfly species *Minois dryas* showed that changes in landscape composition make accurate population estimation very difficult, when the detection probability changes between years. (Pellet & Gander, 2009).

The challenges of variable detection rates between different habitats and between different species are not new. Normally this does not cause a problem, as trends are studied instead of numbers (i.e. transects are compared with themselves through time, not with other transects or other species). However, when a landscape changes, so do the detection chances. Pellet and Gander (2009) combined a mark and recapture study as a baseline, with transect walks in a changing landscape, and found that due to the decreased detection probability the butterfly population was underestimated by 50%; a trend analysis on the normal monitoring data showed a decline of the butterfly population, whereas in reality the population was growing. This was solely due to the decrease in detection chance due to the changing surroundings. They therefore caution against using these methods in systems where the surroundings are changing, e.g. due to land abandonment or restoration. With continued intensification of agriculture in western Europe and land abandonment in eastern Europe, shifts in land use are inevitable; hence methods to deal with the effect of these changes on monitoring are needed, and this could potentially be addressed by using hierarchical modelling (Kéry & Royle, 2015), which allows usage of data points that are clustered instead of independent. As the statistics are already largely developed, but have not been applied to this specific case we estimate the TRL index at 4, technology validated in the lab. Note that this technology can likely be developed quickly.

Potential scope

The development of a hierarchical model capable of quantifying the detection probability per species in a specific habitat could greatly improve trend analyses. Such a technique could also be used to quantify and reduce observer effects. This could potentially improve data quality and make trend analyses possible in areas where the surrounding habitats have changed.

Current status and remaining development time

Hierarchical modelling is already in use, but models that correct for observation chance have not yet been developed. Although this technique is already well developed, we expect the application for insect data to take another 5 to 10 years, because, currently, its development is largely unfunded and being undertaken by experts in ecology and mathematics. If funding is available, this method can potentially be developed in less than a year. The technique, once fully developed, would likely incorporate consecutive repeated visits; the differences between two consecutive visits where circumstances are as similar as possible, would give information on the detectability of a species. In the Netherlands, volunteers counting butterflies are already encouraged to count their route twice on the same day.

Requirements

Once the statistical models are developed and validated, a dataset with repeated visits is required to calculate detection chances per landscape type for each species. It is therefore imperative that the surrounding landscape composition is recorded, even if a transect walk is not repeated.

Estimated costs

The development of the models will likely cost between €30,000 and €50,000, based on ~1 year of staff time of a highly qualified (PhD level) researcher. The operational costs depend on the targeted species groups, as some species groups have to be counted by experts, which would effectively double the costs of regular monitoring. If volunteers are encouraged to make repeated counts, there are no operational costs.

Advantages

By statistically grouping observations we can address the problems with trend estimation when landscapes change, and observer bias can be reduced.

Disadvantages

Insects can flee after disturbance during the first transect walk, and so a rigorous test is needed to show whether there are differences between the first and second count. Alternatively, an observer could wait between counts, but this potentially makes the sampling last longer and cost more.

Possible future development

Once these statistics are fully developed, they could allow observer biases to be better addressed, which could substantially reduce variation in the data and allow for a greater detection power. Additionally, it could allow quantification of the detectability of species, and use these estimates to improve occupancy prediction models.

8.5 Landscape analysis

Description

The habitat of pollinators is important, and aspects such as flower availability, nectar, pollen and host plant density, and microclimatic heterogeneity, can strongly affect their survival. However, the collection of these data on the ground can be extremely time-consuming. Therefore, remote sensing techniques are increasingly being used for landscape analyses. Space- and air-borne sensors are the ones most commonly used. Air-borne sensors range from airplanes to unmanned aerial vehicles (UAVs, reviewed by Goodbody et al., 2017), also popularly called drones. The spatial resolution differs strongly between these approaches, with UAVs reaching sub-millimetre resolution, while satellites are currently limited to a minimum pixel size of ~0.3 m, airplane based measurements are in between.

Remote sensing platforms can have two types of sensors, passive or active. Passive sensors record light (visible and non-visible), active sensors can measure elevation (e.g. LIDAR + InSAR) or structure (SAR). From these sensors a multitude of landscape properties can be derived, such as elevation vegetation type (Roy et al., 2015), chlorophyll content (Kooistra & Clevers, 2016), water content (Gao et al., 2015), biomass (Cunliffe et al., 2016; Lumbierres et al., 2017) and saline stress (Elhag & Bahrawi, 2017). TRL is estimated at 6; the technology is demonstrated in a relevant environment. It is important to note that the TRL strongly depends on the exact application.

Potential scope

Many variables can be derived from remote sensing; however, most studies are strongly area and species dependent, and currently not suitable to be deployed at a pan-European scale without further calibration and validation. However, once properly calibrated, these techniques could offer continuous information on many aspects of small-scale pollinator habitats. In particular, this could include monitoring of vegetation type development, nectar plant availability and small-scale habitat structure, and many other measures could be developed in the near future that could provide valuable information on the status and habitat characteristics of pollinators.

The derivation of these measures from satellite data would be ideal, as it allows for completely automated processing, whereas UAVs and aircraft require a continuous investment. However, satellites are currently limited to a resolution of 0.3m, therefore the choice of platform (UAV, airplane or satellite) strongly depends on the desired resolution. Additionally, optical satellite data strongly depends on the weather (as clouds ruin acquisitions); aircraft or UAV flights are less susceptible to this as their acquisition date is easier to plan.

Pollinator habitat, Tamara Tot

Although it seems likely that the spatial resolution of satellites will improve further, this is expected to be a relatively slow development. There are statistical techniques to improve data called sub-pixel analysis or spectral unmixing (Somers et al., 2011; Veganzones & Grana, 2008), but these too have limitations and will require further development before they can be deployed at a pan-European scale.

Current status and remaining development time

A wide variety of parameters can already be derived from remote sensing. Using UAVs, vegetation can be mapped (Cruzan et al., 2016); for example, the flower richness in peach-tree orchards (Horton et al., 2017) and cotton flowers have been mapped (Xu et al., 2017). However, in these cotton fields the flower count was underestimated because many flowers were hidden by leaves (Xu et al., 2017), which is expected to be a problem in many pollinator habitats. A recent study looking at the landscape matrix as a whole using satellite data found a reasonable relation with in situ collected bee (occupancy) data (Hofmann et al., 2017). The Joint Research Centre (JRC) is currently working with Copernicus to identify landscape features; this could potentially provide valuable landscape data for pollinators.

Currently processing algorithms can derive detailed vegetation properties for small areas, or provide coarse information nationwide. To study pollinators at a pan-European scale, highly detailed information on a large scale is required. The algorithms to establish the vegetation properties will have to be developed and tested further before they can be widely deployed. This is independent of the collection platform, and the differences between countries cannot be addressed by simply increasing the data resolution. We expect this will take between 10 to 15 years, depending on the variable under study. The development of satellites with sufficient resolution to identify individual flowers is expected to take even longer (maybe 15 to 25 years).

Requirements

The requirements of these methods strongly depend on the data collection platform. For UAVs, the most important requirements are the device itself, legal permission to fly (applicable rules will differ between countries), processing software, and computation and storage resources. For airplane and satellite-based remote sensing, only processing software, computation and storage resources are required. All platforms require the development of new algorithms to process data on a large scale. The complexity of these algorithms depends on the variable(s) to be derived.

Estimated costs

The cost of these methods varies greatly, and strongly depends on the desired information and therefore the most appropriate platform, spatial and temporal resolution. Currently, a high resolution (0.5m) commercial satellite image costs ~15€ per km^2, and a temporal resolution of four times a year is required for most variables. Therefore, monitoring a single site would cost about €300 (assuming 5 km^2 per site); note that this does not include any processing or analysis. Aerial photography costs about 10€ per km^2, and would therefore cost about €200 per year per site. A UAV costs about €2,000 to buy. Assuming one UAV can be shared between 10 sites, this would cost about €200 per site for the first year. It is important to recognise that the UAV will have operating costs, which are not currently included here as they are highly variable depending upon type and application, whereas operating costs are already included in the other methods in this chapter. All methods need additional data processing by a technician with at least graduate level education, and storage facilities.

Advantages

Remote sensing is likely to become a cheap and effective way to monitor landscape composition and development on a large scale. It is not necessary to negotiate access to areas, and a large number of variables can be automatically collected. It is likely that high resolution landscape data could be useful in various other (not pollinator-related) studies.

Disadvantages

The disadvantages are mainly platform dependent. Although rules are country dependent, the regulations for UAVs are increasingly strict; in most European countries, rules are already in place (Stöcker et al., 2017). Rules will likely differ between countries, making this method difficult to deploy in a multi-country monitoring scheme. Aerial photography strongly depends upon the availability, pricing and schedule of specialised companies. Satellites can collect data only at set times, and cannot change their trajectory when the weather is unsuitable for data collection (e.g. clouds). The resolution of satellites has to improve before landscape characteristics, such as flower richness, can be estimated reliably on a large scale. Additionally for all platforms, only the top 'layer' of vegetation is observed, and this can induce errors when estimating particular vegetation properties, such as flower richness (Xu et al., 2017). This could be partially addressed in the processing phase, but a top-down view might not contain all the information (e.g. in dense forests with closed canopy). Finally, reliable algorithms to identify flowers are not yet available, and it remains unclear if the top layer of vegetation will have sufficient information to identify species or establish individual flower counts. It is also important to note that although a detailed flower count would be very valuable, it does not necessarily translate directly into nectar or pollen availability or habitat quality.

Possible future development

A high-resolution dataset on numerous landscape properties, such as flower and nectar or pollen availability, vegetation type and vegetation development, could be very valuable, as it can also help identify possible causes behind decline and hence potential beneficial management.

8.6 DNA barcoding

Description

DNA barcoding is a method using sequence variation in short gene regions (DNA barcodes) to identify a single species. This is done through four steps: (i) DNA is isolated from a sample; (ii) the DNA barcode region is amplified using Polymerase Chain Reaction (PCR); (iii) the PCR products are sequenced; and, (iv) the resulting sequences are compared with reference databases to find a matching species. A 648 base pair region (648 is used mostly but regions can range from 500 to 1000) of the cytochrome *c* oxidase I (COI) gene forms the primary barcode sequence for members of the animal kingdom (Ratnasingham & Hebert, 2013). However, not all species can be distinguished from this base pair region. Other primers are rapidly being developed. Interpretation of sequenced results require an expert in bioinformatics. DNA barcoding does not give species as an output but Operational Taxonomic Units (OTU), and taxonomic experts are needed to interpret the results (Piper et al., 2019). The TRL is estimated at 7; the technique has been demonstrated in the operational environment. The lack of complete reference databases prevents it from reaching the next level (TLR 8, system complete and qualified).

Potential scope

DNA barcoding can potentially be used to identify species from only a small fraction of a specimen (e.g. a leg or a wing). The method reduces the dependence on knowledgeable species experts for identification of species that are difficult to distinguish morphologically. It can also help discover new species. However, it is important to maintain expertise in taxonomy and classical diagnostics to complement methods such as DNA barcoding or DNA metabarcoding (Piper et al., 2019). A proof of concept using this technique in combination with pan trapping is available (Creedy et al., 2020). There are no complete reference databases on DNA barcodes, and there will always be a need to confirm identification of certain species through morphological examination.

Current status and remaining development time

The technique is currently in use, however its applicability is limited by the availability of barcoded species in the reference databases (see section 7.1). To use this technique on a pan-European scale, all European species have to be listed in well-curated databases (see section 7.2.4), such as INSDC (International Nucleotide Sequence Database Collaboration), which includes Genbank, ENA (European Nucleotide Archive), and DDBJ (Dna Data Bank Japan). Other examples are Consortium for the Barcode of Life (CBOL) and International Barcode of Life (iBOL)[6]. CBOL was initiated by the University of Guelph and launched in 2004. Its aim was to promote DNA barcoding as a new scientific standard (Ratnasingham & Hebert, 2007). The iBOL project began in 2007, and is a research alliance of nations with the aim to "Create a digital identification system for life that is accessible to everyone". The iBOL is now a consortium with 32 member nations and 8 associate member nations. The member nations are represented by networks of researchers or organisations in a country that are engaged in or supporting DNA barcoding as part of iBOL. Among European countries members or associate members are: Austria, Belarus, Bulgaria, Finland, France, Germany, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Switzerland, Turkey and the UK. In the first programme of iBOL called Barcode 500K, 500,000 species were barcoded between 2010 and 2015, the next step is Bioscan which was started in 2019 and will end in 2026, with the aim to barcode another 2 million species.

Another initiative is BOLD[7] (Ratnasingham & Hebert, 2007, 2013). Data are both entered directly into BOLD and gathered from other national databases. Among the species of interest here are bees, butterflies and hoverflies, and the proportion of described species with DNA barcodes varies between groups. A relatively high proportion of Lepidoptera species already have DNA barcodes. As of November 2019, 57 % of the 165,000 Lepidopteran species described worldwide have DNA barcodes in

6 https://ibol.org/
7 http://www.boldsystems.org/

reference databases[8]; for European species this is likely higher. About 2,383 species in the family Syrphidae (hoverflies) have DNA barcodes, of which data for 2,007 species are publically available, and there are currently about 6,000 described species in the family. In the order Hymenoptera there are over 150,000 described species, and 34,918 species with DNA barcodes, of which data for 30,838 species are publically available. For Apidae, which is the largest family of bees, there are 2,626 species with barcodes; public data are available for 1,451 species and there are at least 5,700 described species[9].

Requirements

Once samples are collected minor pre-processing can be conducted at a local institute before sending the samples off to a specialised lab. Here the DNA is sequenced and the data are returned. These data have to be processed and interpreted by staff trained in bioinformatics and taxonomy respectively. The requirements therefore are: (i) minimal training of volunteers who collect the data; (ii) a specialised lab to sequence the samples; and, (iii) experts to interpret the data.

Estimated costs

The costs of DNA processing are rapidly decreasing, and strongly depend on the primers and the number of samples. Roughly the costs are estimated between €10 to €100 per sample based on previous studies (Sabino-Pinto et al., 2019; Breeze et al., 2020).

Advantages

The collection can be done by volunteers. It is possible to identify species in all developmental stages using their DNA. Species experts are not needed for species identification to the same extent as with morphological species identification. It is possible to obtain DNA by collecting only a small part of a specimen, so the method does not necessarily have to be destructive. Therefore, if insects are collected, the use of only a small piece of the insect as a DNA sample makes it possible to keep the specimen more or less intact as a reference.

Disadvantages

Not all species can be found in the reference databases; and as with all databases, these databases have to be rigorously maintained and checked before use. Specimens (or a small part of them) need to be collected to obtain DNA. Specialised laboratories are required for the DNA sequencing and experts have to be available to interpret the resulting data. There are several database initiatives, and there may be more data available than the BOLD data presented here. However, before they can be used, these data will have to be combined and centralised.

Possible future development

The costs are expected to decrease further, and the entire process will likely become more efficient. The step from OTU to taxonomy could potentially be automated. Once reference libraries are sufficiently built up, it might be possible to send samples to the lab and receive their taxonomic information directly.

8.7 DNA metabarcoding

Description

The term DNA metabarcoding is used for barcoding of samples containing DNA from more than one organism. The method can be used to identify species, for example, in mass collections of species, in water, air and soil samples, in faeces (to find out what a specimen has eaten) or pollen samples (to find out from which plant species pollen has been collected). The method combines DNA-based identification and high-throughput DNA sequencing. It uses universal PCR primers to mass-amplify DNA barcodes from mass collections of organisms or from environmental DNA (eDNA). The TRL of this technique is estimated at level 5, the technique having been validated in a relevant environment.

Potential scope

DNA-based methods can potentially be used in environmental monitoring. Since metabarcoding allows simultaneous multi-species identification of complex mixed communities it may be a means to scale up insect surveillance through

8 http://lepbarcoding.org/
9 http://www.boldsystems.org/

increasing the number of traps that can be processed within a certain time. It is possible to identify individual species in a sample of many species, given that the DNA sequences for the species are available in a reference database. It is also to some extent possible to estimate the abundance of different species in a sample (Piper et al., 2019). This method could be used to reduce the time for sorting and species identification of samples from Malaise or pan traps for instance. Potentially the collection fluid from pan traps could be tested rather than the species themselves using eDNA techniques. It could also allow for identification of species that cannot be identified by post-mortem morphological examination. It has also been suggested that DNA metabarcoding could be tailored for the detection of invasive insects in surveillance (Piper et al., 2019).

Metabarcoding can also be used to study plant-pollinator networks through identifying pollen samples from different insect species. This is a method that has been tested in several studies in different landscape contexts and seems to work quite well (Bell et al., 2017; Galliot et al., 2017; Lucas et al., 2018). Pollen may also be collected from specimens in old collections of insects, such as museums, to determine historical plant-pollinator networks (Gous et al., 2019). The identification of plant species through DNA analyses of pollen samples depends on the availability of comprehensive barcode reference databases (Galliot et al., 2017; Gous et al., 2019). The information on plant-pollinator networks obtained through DNA analyses of pollen samples may have implications for the design of agri-environment schemes (Gresty et al., 2018). DNA barcoding has also been used for species determination of insects visiting 'sticky flowers', which are placed among the targeted plant species. Under this method flower visiting insects that visit these flowers get stuck (Tiusanen et al., 2016). This is a way to potentially determine which species are the main pollinators of certain plant species.

When working with metabarcoding it is important to keep research set up and corresponding biases in mind, because several studies have pointed out these biases can lead to erroneous conclusions (Bálint et al., 2016; Dickie et al., 2018; Nilsson et al., 2019; Zinger et al., 2019). Common problems are failure to capture the full taxonomic diversity in the spatial distribution of sampling locations, or failure to adequately protect samples in transport which can affect certain species more than others. The way samples are taken (filter on water collector, root removal from soil sample) can also have a significant influence on the results (Zinger et al., 2019). The choice of primer and reference database availability are also a potential source of error (Aylagas et al., 2018). One study even found that of the 75 reviewed studies incorporating metabarcoding, only 5% were methodologically sound and repeatable (Dickie et al., 2018).

Current status and remaining development time

The methods are under rapid development and will probably be more readily available for a wider range of users in the foreseeable future (Piper et al., 2019). Thus, this method should already be taken into account now, and samples collected and stored in a way that makes it possible to use DNA metabarcoding as a means for later species determination. The sampling of insects on a European scale could also contribute to building up the available DNA barcode reference libraries, so that DNA metabarcoding may become a more accurate method for species determination in the future.

Requirements

Similar to regular DNA barcoding, collection and pre-processing can be conducted by minimally trained volunteers. Samples have to be processed at a specialised lab and data interpretation has to be done by experts in bioinformatics and taxonomy, although continued developments are making this more accessible to non-experts. As more data are produced per sample, a larger technical infrastructure and storage capacity is required.

Estimated costs

The costs for processing a metabarcoding sample are rapidly decreasing (Zinger et al., 2019). The costs of processing samples for the reference databases are about €5 per species (not including expert costs for manual identification). The costs of processing samples will likely have a similar cost per species in the sample, although new techniques are continuously being developed that could potentially make this cheaper (Wang et al., 2018).

Advantages

Similar to the regular DNA processing, the collection can be done by volunteers with minimal training. Once reference databases are available species can be identified without expert knowledge, although expert knowledge is required to interpret the processed DNA data. Additionally, this technique could potentially give insight into plant-pollinator relations when pollen DNA is also extracted.

Disadvantages

Currently not all species are available in the reference databases, and therefore cannot be identified. Specimens need to be collected to obtain DNA, although work on environmental DNA looks promising. There are potential problems with sample contamination as well as false positives (detecting a species that is not present) and false negatives (missing a species that is present) (Piper et al., 2019). Different precautions need to be taken to minimise these errors (see Piper et al. 2019 for a review). Currently, this technique can only give an indication of species abundances, and can only reliably be used for establishing occupancy.

Possible future development

Once comprehensive reference databases are available for most European pollinator species and the problems with establishing abundance are resolved, this approach could provide a huge step forward towards understanding local pollinator community composition and the size of individual populations as well as their interaction with plants through pollen analysis.

References

Aylagas E, Borja Á, Muxika I, & Rodríguez-Ezpeleta N (2018) Adapting metabarcoding-based benthic biomonitoring into routine marine ecological status assessment networks. *Ecological Indicators*, *95*, 194–202.

Bálint M, Bahram M, Eren AM, Faust K, Fuhrman JA, Lindahl B, … Unterseher M (2016) Millions of reads, thousands of taxa: microbial community structure and associations analyzed via marker genes. *FEMS Microbiology Reviews*, *40*(5), 686–700.

Bargoti S, & Underwood J (2017) Deep fruit detection in orchards. *2017 IEEE International Conference on Robotics and Automation (ICRA)*, 3626–3633. IEEE.

Bell KL, Fowler J, Burgess KS, Dobbs EK, Gruenewald D, Lawley B, … Brosi BJ (2017) Applying pollen DNA metabarcoding to the study of plant–pollinator interactions. *Applications in Plant Sciences*, *5*(6), 1600124.

Creedy TJ, Norman H, Tang CQ, Qing Chin K, Andujar C, Arribas P, … Vogler AP (2020) A validated workflow for rapid taxonomic assignment and monitoring of a national fauna of bees (Apiformes) using high throughput DNA barcoding. *Molecular Ecology Resources*, *20*(1), 40–53.

Cruzan MB, Weinstein BG, Grasty MR, Kohrn BF, Hendrickson EC, Arredondo TM, & Thompson PG (2016) Small unmanned aerial vehicles (micro-UAVs, drones) in plant ecology. *Applications in Plant Sciences*, *4*(9).

Cunliffe AM, Brazier RE, & Anderson K (2016) Ultra-fine grain landscape-scale quantification of dryland vegetation structure with drone-acquired structure-from-motion photogrammetry. *Remote Sensing of Environment*, *183*, 129–143.

Dickie IA, Boyer S, Buckley HL, Duncan RP, Gardner PP, Hogg ID, … Morales SE (2018) Towards robust and repeatable sampling methods in eDNA-based studies. *Molecular Ecology Resources*, *18*(5), 940–952.

Ding W, & Taylor G (2016) Automatic moth detection from trap images for pest management. *Computers and Electronics in Agriculture*, *123*, 17–28.

Elhag M, & Bahrawi JA (2017) Soil salinity mapping and hydrological drought indices assessment in arid environments based on remote sensing techniques. *Geoscientific Instrumentation, Methods and Data Systems*, *6*(1), 149–158.

Gagliano M (2013) The flowering of plant bioacoustics: how and why. *Behavioral Ecology*, *24*(4), 800–801.

Galliot JN, Brunel D, Bérard A, Chauveau A, Blanchetête A, Lanore L, & Farruggia A (2017) Investigating a flower-insect forager network in a mountain grassland community using pollen DNA barcoding. *Journal of Insect Conservation*, *21*(5–6), 827–837.

Gao Y, Walker JP, Allahmoradi M, Monerris A, Ryu D, & Jackson TJ (2015) Optical sensing of vegetation water content: A synthesis study. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *8*(4), 1456–1464.

Goodbody TRH, Coops NC, Marshall PL, Tompalski P, & Crawford P (2017) Unmanned aerial systems for precision forest inventory purposes: A review and case study. *The Forestry Chronicle*, *93*(1), 71–81.

Gous A, Swanevelder DZH, Eardley CD, & Willows-Munro S (2019) Plant–pollinator interactions over time: Pollen metabarcoding from bees in a historic collection. *Evolutionary Applications*, *12*(2), 187–197.

Gradišek A, Slapničar G, Šorn J, Luštrek M, Gams M, & Grad J (2017) Predicting species identity of bumblebees through analysis of flight buzzing sounds. *Bioacoustics*, *26*(1), 63–76.

Gresty CEA, Clare E, Devey DS, Cowan RS, Csiba L, Malakasi P, ... Willis KJ (2018) Flower preferences and pollen transport networks for cavity-nesting solitary bees: Implications for the design of agri-environment schemes. *Ecology and Evolution*, *8*(15), 7574–7587.

Grill T, & Schlüter J (2017) Two convolutional neural networks for bird detection in audio signals. *2017 25th European Signal Processing Conference (EUSIPCO)*, 1764–1768. IEEE.

Hill AP, Prince P, Snaddon JL, Doncaster CP, & Rogers A (2019) AudioMoth: A low-cost acoustic device for monitoring biodiversity and the environment. *HardwareX*, *6*, e00073.

Hofmann S, Everaars J, Schweiger O, Frenzel M, Bannehr L, & Cord AF (2017) Modelling patterns of pollinator species richness and diversity using satellite image texture. *PloS One*, *12*(10), e0185591.

Horton R, Cano E, Bulanon D, & Fallahi E (2017) Peach flower monitoring using aerial multispectral imaging. *Journal of Imaging*, *3*(1), 2.

Isaac NJB, Cruickshanks KL, Weddle AM, Marcus Rowcliffe J, Brereton TM, Dennis RL. H, ... Thomas CD (2011) Distance sampling and the challenge of monitoring butterfly populations. *Methods in Ecology and Evolution*, *2*(6), 585–594.

Kadlec T, Tropek R, & Konvicka M (2012) Timed surveys and transect walks as comparable methods for monitoring butterflies in small plots. *Journal of Insect Conservation*, *16*(2), 275–280.

Kéry M, & Royle JA (2015) *Applied Hierarchical Modeling in Ecology: Analysis of distribution, abundance and species richness in R and BUGS: Volume 1: Prelude and Static Models*. Academic Press.

Kooistra L, & Clevers JGPW (2016) Estimating potato leaf chlorophyll content using ratio vegetation indices. *Remote Sensing Letters*, *7*(6), 611–620.

Lee SH, Chan CS, Wilkin P, & Remagnino P (2015) Deep-plant: Plant identification with convolutional neural networks. *2015 IEEE International Conference on Image Processing (ICIP)*, 452–456. IEEE.

Lucas A, Bodger O, Brosi BJ, Ford CR, Forman DW, Greig C, ... De Vere N (2018) Generalisation and specialisation in hoverfly (Syrphidae) grassland pollen transport networks revealed by DNA metabarcoding. *Journal of Animal Ecology*, *87*(4), 1008–1021.

Lumbierres M, Méndez P, Bustamante J, Soriguer R, & Santamaría L (2017) Modeling biomass production in seasonal wetlands using MODIS NDVI land surface phenology. *Remote Sensing*, *9*(4), 392.

Mac Aodha O, Gibb R, Barlow KE, Browning E, Firman M, Freeman R, ... Newson SE (2018) Bat detective—Deep learning tools for bat acoustic signal detection. *PLoS Computational Biology*, *14*(3), e1005995.

Nilsson RH, Anslan S, Bahram M, Wurzbacher C, Baldrian P, & Tedersoo L (2019) Mycobiome diversity: high-throughput sequencing and identification of fungi. *Nature Reviews Microbiology*, *17*(2), 95–109.

Pellet J, & Gander A (2009) Comparaison de méthodes pour l'estimation de l'abondance des populations de papillons de jour: établissement d'un protocole de suivi du Grand Nègre des bois (Minois dryas (Scopoli, 1763)) sur la rive sud du lac de Neuchâtel. *Entomo Helvetica-Entomologische Zeitschrift Der Schweiz*, *2*, 201–216.

Piper AM, Batovska J, Cogan NOI, Weiss J, Cunningham JP, Rodoni BC, & Blacket MJ (2019) Prospects and challenges of implementing DNA metabarcoding for high-throughput insect surveillance. *GigaScience*, *8*(8), giz092.

Ratnasingham S, & Hebert PDN (2007) BOLD: The Barcode of Life Data System (http://www. barcodinglife. org). *Molecular Ecology Notes*, *7*(3), 355–364.

Ratnasingham S, & Hebert PDN (2013) A DNA-based registry for all animal species: the Barcode Index Number (BIN) system. *PloS One*, *8*(7), e66213.

Riabchenko E, Meissner K, Ahmad I, Iosifidis A, Tirronen V, Gabbouj M, & Kiranyaz S (2016) Learned vs. engineered features for fine-grained classification of aquatic macroinvertebrates. *2016 23rd International Conference on Pattern Recognition (ICPR)*, 2276–2281. IEEE.

Roy PS, Behera MD, Murthy MSR, Roy A, Singh S, Kushwaha SPS, … Reddy CS (2015) New vegetation type map of India prepared using satellite remote sensing: Comparison with global vegetation maps and utilities. *International Journal of Applied Earth Observation and Geoinformation*, *39*, 142–159.

Royer RA, Austin JE, & Newton WE (1998) Checklist and “Pollard walk” butterfly survey methods on public lands. *The American Midland Naturalist*, *140*(2), 358–372.

Sa I, Ge Z, Dayoub F, Upcroft B, Perez T, & McCool C (2016) Deepfruits: A fruit detection system using deep neural networks. *Sensors*, *16*(8), 1222.

Sabino-Pinto J, Krause ET, Bletz MC, Martel A, Pasmans F, Steinfartz S, & Vences M (2019) Detectability vs. time and costs in pooled DNA extraction of cutaneous swabs: a study on the amphibian chytrid fungi. *Amphibia-Reptilia*, *40*(1), 29–39.

Singh J, & Joshi R (2019) Background Sound Classification in Speech Audio Segments. *2019 International Conference on Speech Technology and Human-Computer Dialogue (SpeD)*, 1–6. IEEE.

Somers B, Asner GP, Tits L, & Coppin P (2011) Endmember variability in spectral mixture analysis: A review. *Remote Sensing of Environment*, *115*(7), 1603–1616.

Steen R (2017) Diel activity, frequency and visit duration of pollinators in focal plants: in situ automatic camera monitoring and data processing. *Methods in Ecology and Evolution*, *8*(2), 203–213.

Steenweg R, Hebblewhite M, Kays R, Ahumada J, Fisher JT, Burton C, … Whittington J (2017) Scaling-up camera traps: Monitoring the planet’s biodiversity with networks of remote sensors. *Frontiers in Ecology and the Environment*, *15*(1), 26–34.

Stöcker C, Bennett R, Nex F, Gerke M, & Zevenbergen J (2017) Review of the current state of UAV regulations. *Remote Sensing*, *9*(5), 459.

Tiusanen M, Hebert PDN, Schmidt NM, & Roslin T (2016) One fly to rule them all—muscid flies are the key pollinators in the Arctic. *Proceedings of the Royal Society B: Biological Sciences*, *283*(1839), 20161271.

Tran DT, Høye TT, Gabbouj M, & Iosifidis A (2018) Automatic Flower and Visitor Detection System. *2018 26th European Signal Processing Conference (EUSIPCO)*, 405–409. IEEE.

Veganzones MA, & Grana M (2008) Endmember extraction methods: A short review. *International Conference on Knowledge-Based and Intelligent Information and Engineering Systems*, 400–407. Springer.

Veits M, Khait I, Obolski U, Zinger E, Boonman A, Goldshtein A, … Estlein P (2019) Flowers respond to pollinator sound within minutes by increasing nectar sugar concentration. *Ecology Letters*, *22*(9), 1483–1492.

Wang WY, Srivathsan A, Foo M, Yamane SK, & Meier R (2018) Sorting specimen-rich invertebrate samples with cost-effective NGS barcodes: Validating a reverse workflow for specimen processing. *Molecular Ecology Resources*, *18*(3), 490–501.

Xu R, Paterson A, & Li C (2017) Cotton flower detection using aerial color images. *2017 ASABE Annual International Meeting*, 1. American Society of Agricultural and Biological Engineers.

Zinger L, Bonin A, Alsos IG, Bálint M, Bik H, Boyer F, … Deagle BE (2019) DNA metabarcoding—Need for robust experimental designs to draw sound ecological conclusions. *Molecular Ecology*, *28*(8), 1857–1862.

9 Next Steps Towards the EU Pollinator Monitoring Scheme

A design for a Minimum Viable Scheme (MVS) and additional modules for monitoring pollinators across Europe are presented in Chapter 5. Additional pilot work in several areas would be beneficial in order to finalise detailed aspects of the design (section 9.1). The outcome of such pilot work would inform on the final scheme design, and an outline of how the scheme could be implemented across Europe is discussed in section 9.2.

9.1 Recommended pilot work

Our proposal used the best available evidence and knowledge to provide a design for a pan-European pollinator monitoring scheme. However, a number of important knowledge gaps remain which would need to be addressed in order to fine-tune and further improve the design. We therefore recommend a series of pilot studies to be carried out to refine methodologies, extend the power analysis of existing survey data, field test additional modules to the MVS, test and validate new indicators, explore pathways to integrate emerging technologies, and increase the taxonomic and recorder capacity to support the monitoring scheme.

9.1.1 Methods' refinement for the Core Scheme

The sampling intensities proposed for the methods in the scheme (i.e. number of pan traps and transects, and repetition through a season) were informed by an analysis of existing large-scale pollinator surveys (section 5.1). However, these datasets tended to be biased towards northern and western Europe, with fewer studies in the Mediterranean and eastern Europe. In particular, southern European countries generally have higher pollinator species diversity (section 3.1) and turnover through the season (i.e. within a year) and between years, and between sites, and so sampling regimes would need to ensure this variability was captured sufficiently well. Therefore it will be important to conduct pilot studies in these under-represented areas to assess the minimum number of pan traps, transects and temporal replications needed; such a pilot would require a minimum of 2 years but would ideally be longer.

In parallel, a power analysis of new data collected during the pilot and any further datasets from existing monitoring programmes that could help inform on the sampling intensities is required. Further, piloting the MVS using existing site networks (e.g. EMBAL or LUCAS, section 5.2.2) should be conducted to evaluate the feasibility of using this approach across Europe. Such a pilot would need to ascertain, for example, whether sufficient data on vegetation type and change in floral cover were captured by the EMBAL or LUCAS networks and available at relevant scales to help explain variation in pan trap catches or on transect walks. In addition,

Thyreus ramosus, Nicolas J. Vereecken


Collecting pollinators, Tamara Tot

a field assessment of the effects of floral context on pan trap sampling should be conducted. This should include a direct comparison of species and abundance data from pan traps paired with standardised transect walks along gradients of floral resource availability, in a small number of MS from different biogeographic zones. Informed by the outcome of this study, standardised methods to assess local floral resources, at the appropriate scale(s), should be developed and tested for inclusion in the MVS.

The ongoing expansion of the European Butterfly Monitoring Scheme has the potential to support and integrate with EU-PoMS, and as such should be assessed to identify how far eBMS sites could be included in the EU-PoMS. eBMS uses a citizen science approach and allows surveyors to select sites. Even though this inevitably introduces spatial-temporal bias which requires model-based correction to produce national and European level trends, it could provide a basis for expansion to include other pollinator groups as part of the MVS.

Finally, all cost estimates should be refined based on the results of the methods piloting.

9.1.2 Methods' development for a pollination services module

To finalise a robust design for pollination service monitoring we recommend that our proposed methods of crop flower visitor counts and analyses of known crop pollinators from pan traps (section 5.4.1) would require: (i) field testing various indirect methods for assessing pollination against a direct measure of crop pollination (such as bagging experiments; sections 5.4.1 and 6.1.3.2) in a range of pollinator-dependent crops across Europe; (ii) further analysis of existing datasets to improve our understanding of the relative importance of different pollinators across Europe, such as extending the work of Kleijn et al. (2015) to other taxa beyond bees, so that the most important crop pollinating species can be targeted when assessing species trends and developing indicators; (iii) using a combination of new field data and analysing existing studies to develop a sampling design to provide effective coverage of major pollinator-dependent crops in different countries; and, (iv) designing and testing of methodologies to allow an estimation of pollination of wildflowers through either visitor counts, bagging experiments or use of sentinel plants.

9.1.3 Methods' development for a moth module

We recommend running a series of field trials in a representative range of European countries and habitats to assess the minimum number of traps per site and trapping sessions per year needed to survey moths reliably (section 5.3.1). This, in conjunction with power analyses of existing moth survey data, would help underpin a robust design for an additional module to the full scheme. There is also scope to field test and refine the moth trapping equipment with a view to producing a standardised design to be adopted across Europe.

9.1.4 Methods development for a flower visitor module

Running a series of pilot projects in a variety of countries would allow tailoring of the established Flower-Insect Timed counts (section 5.4.2) by adapting the lists of target flowers and insect groups to national contexts. This is likely to be particularly important for those Member States with a very high floral and insect diversity such as in the Mediterranean. These pilot data would help inform on the co-development of field methodologies, training materials and resources needed to add this module to the EU-PoMS.

9.1.5 Methods development for a wider insect biodiversity module

Malaise traps have the advantage of capturing a very wide array of flying insects, some of which are pollinators, but widespread deployment poses challenges of identification of bulk samples and the relatively high maintenance and costs of Malaise traps. However, this method offers a leading approach to assessing wider insect biodiversity (section 5.4.3) and some trapping schemes are already operating in a few European countries, such as Germany, Sweden and Spain. We therefore recommend pilot work to compare the pollinator component of Malaise trapping against the methods of the MVS at a series of shared sites in a range of habitats and countries. Further, a deeper assessment of the methods for species identifications, in terms of accuracy and costs per individual, would provide insights into the potential for Malaise traps to provide data on some additional species and trends which may not be available through the Core Scheme.

9.1.6 Testing and calibration of general and CAP pollinator indicators

A framework and indicators for the MVS are presented in chapter 6, and these would benefit from pilot work linked to existing research/monitoring infrastructure to test and calibrate derived MVS indicators against values generated independently. Piloting the MVS at sites where data on a range of measures (e.g. State, Impact and Pressure indicators) are already being collected could help refine the indicators. In particular, the exploitation of ongoing work assessing the effectiveness of CAP measures for pollinators, either though empirical or modelling work, could inform on the use of CAP indictors in the Core Scheme.

An evaluation of the impact of the CAP on pollinators and pollination requires a targeted or question driven monitoring approach (sections 1.2.1 and 6.2.2). Finding the best monitoring sites in adequate numbers (which may require additional sites to those used in the surveillance monitoring under the MVS), and the most informative set of indicators for the respective CAP measures,

Macroglossum stellatarum, Adara Pardo

Eristalis tenax, Tamara Tot

requires an ex-ante evaluation of the potential effects of the targeted, needs-based measures and interventions decided by the Member States. An example of such an approach used a gradient of agri-environment scheme uptake to test impacts on mobile species, including pollinators[1] Clear and informative hypotheses about the most likely impacts of the CAP are required for setting up a CAP impact indicator monitoring (section 6.2); the Delphi-study by Cole et al. (2020) provides an example of an approach which could be adapted to generate specific hypotheses for evaluation. For the post-2020 CAP, such a Delphi-study would ideally be conducted for each Member State before the implementation of the CAP measures to provide the necessary basis for the development of the specific evaluation schemes.

9.1.7 Assessing the potential of emerging technologies

There are a variety of technologies in various stages of development which offer important opportunities to support an EU pollinator monitoring scheme (Chapter 8). These are in various stages of technological development, ranging from early prototypes through to successful application in specific contexts. We therefore recommend an active vigil of these technologies to identify the point at which they are ready to be tested in a pilot programme with a view to integrating them into the MVS; in parallel, an active approach to identify ways to support and accelerate the development of promising new technologies is recommended. For instance, image analysis and sound recognition approaches for automatically identifying pollinators in the field (sections 8.2 and 8.3) will soon be at the stage where they can be tested and calibrated against established field methods. In contrast, DNA barcoding and meta-barcoding approaches (sections 8.6 and 8.7) are well-established methods, but need coordinated trans-national efforts to improve molecular sequence libraries through targeted gap filling of poorly represented species, and standardised methods to allow seamless integration into monitoring programmes. Finally, there are several specific recommendations on the development of approaches and materials to enhance the taxonomic capacity of Member States which could also benefit from pilot work (Chapter 7).

9.1.8 Engaging with citizen scientists

The proposed MVS relies heavily on substantial citizen scientist participation in conjunction with professionals. While some parts of Europe have strong traditions of citizen science and volunteer recorders (e.g. the Netherlands, Germany, Ireland and the UK), many parts of Europe, especially in the Mediterranean and eastern states, currently lack this. It is therefore

1 http://randd.defra.gov.uk/Document.aspx?Document=14162_AES_landscape_monitoring_scoping_study_final_report.pdf

Phasia hemiptera, Axel Hochkirch

important to look at various pathways to raise awareness of the general public about citizen science and monitoring, engage with and support existing citizen science groups and volunteer-based recording schemes, provide resources to help establish new networks and recorder groups, and better understand the motivations of individuals with respect to recruiting and retaining recorders. Developing best practice approaches from countries with well-established citizen science communities and piloting these in areas where there is a current shortfall will help guide capacity building efforts in the longer-term. In parallel, a careful assessment is needed of: the range of capabilities of volunteers; the knowledge and expertise different MVS sampling methods (e.g. pan traps, transects) and specimen identification require from volunteers; and, how training can best be implemented to citizen scientists.

9.1.9 Testing specific efforts for monitoring rare and threatened species

In the light of the declining status of many pollinators in Europe, and the lack of data regarding their conservation status (section 1.1), we strongly recommend additional surveying and monitoring of rare and threatened species (section 5.3.2) as an essential complement to the MVS. This work should focus on species that are listed as Critically Endangered or Data Deficient on the European Red Lists, in order to obtain better data on their distribution, population status, ecology and threats. These data will be crucial to obtain up-to-date Red List assessments in the near future.

9.2 Forward perspective

This report presents a cohesive framework and approach for establishing a pollinator monitoring scheme across Europe. The expert group used a wide range of high quality data and knowledge available at the time, and with feedback from stakeholders, developed a scheme able to deliver high quality monitoring data on the status and trends of pollinators across Europe. However, such a scheme is ambitious and has never been attempted before at such a scale, and so there are important opportunities for refinement and improvement.

Member States are starting from very different positions in terms of: taxonomic capacity to support a scheme; availability of citizen scientists to participate; extent of existing pollinator monitoring and research activities; infrastructure to handle large numbers of insect samples (e.g. natural history museums); knowledge of national pollinator species and threat status; and bioclimatic conditions across their land area. Given the diversity of starting conditions, we expect adoption of the MVS to follow a tiered approach, with some Member States: (i) more or less ready to establish a full scheme within one or two years; (ii) requiring an initial preparation phase and pilot work for a short period to help inform and fine-tune the scheme before full roll out; and (iii) needing substantial capacity building and preparation in order to adopt a scheme in the short- to medium-term.

The establishment and expansion of the European Butterfly Monitoring Scheme has successfully used this approach with phased implementation across Europe.

For the EU-PoMS, in all cases, there will be a critical learning-by-doing element where initial implementation work will help inform and improve the later rollout of the scheme. The scheme will require some tailoring, as the effect of the diversity of Member State starting points starts to be realised, but at a minimum all Member States have the ability to adopt a pilot scheme in the first year, with many going far beyond this. A second phase of feedback and refinement of the MVS through experts working closely with Member State representatives will be needed to optimise the scheme after the first few years. The pilot data will allow for a direct test of how well the scheme is able to meet its stated objectives to monitor pollinator trends across the EU. Once in place, the full scheme will ensure Europe and its Member States are uniquely positioned to have the highest quality data on the status and trends of a wide range of pollinators and pollination services as a robust basis for management and policy decision making.

References

Cole LJ, Kleijn D, Dicks LV, Stout JC, Potts SG, Albrecht M, Balzan MV, … Scheper J (2020) A critical analysis of the potential for EU Common Agricultural Policy measures to support wild pollinators on farmland. Journal of Applied Ecology 57: 681– 694

Kleijn D, Winfree R, Bartomeus I, Carvalheiro LG, Henry M, Isaacs R, Klein A-M, Kremen C, M'Gonigle LK, Rader R, Ricketts T, Williams NM, Adamson NL, … Potts SG (2015) Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications 6: 7414

A1: Profile of EU Member States and UK

This appendix provides a summary for each Member State of the estimated **number of species of bees, butterflies and hoverflies** and whether **national Red Lists** are available for these taxa. The **number of sites** is the minimum required to detect a 30-50% decline in the EU over 10 years (see Chapter 5 for details). An **estimated cost** in Euros is provided for the: establishment of a national pollinator monitoring scheme, its annual implementation, and the expected capacity building needed to support such a scheme.

Austria	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	709 205 419
Red List for: Bees **Butterflies** **Hoverflies**	Planned Yes No
Number of monitoring sites needed:	45
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€6,000 €345,000 €376,000

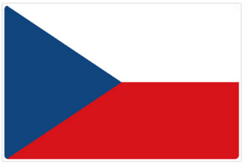
Belgium	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	405 112 341
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	23
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€3,000 €174,000 €179,000

Bulgaria	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	716 217 269
Red List for: Bees **Butterflies** **Hoverflies**	No Yes No
Number of monitoring sites needed:	56
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€7,000 €176,000 €423,000

Croatia	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	725 196 230
Red List for: Bees **Butterflies** **Hoverflies**	No Yes No
Number of monitoring sites needed:	34
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€5,000 €108,000 €401,000

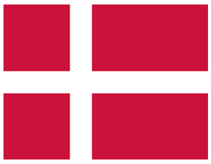
Cyprus	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	369 48 70
Red List for: Bees **Butterflies** **Hoverflies**	No No No
Number of monitoring sites needed:	14
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€2,000 €69,000 €294,000

Czechia



Estimated number of species of: Bees **Butterflies** **Hoverflies**	590 157 401
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes Yes
Number of monitoring sites needed:	43
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€6,000 €159,000 €182,000

Denmark



Estimated number of species of: Bees **Butterflies** **Hoverflies**	291 84 301
Red List for: Bees **Butterflies** **Hoverflies**	No Yes No
Number of monitoring sites needed:	28
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€4,000 €227,000 €141,000

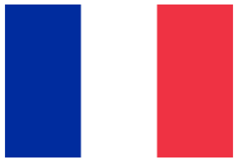
Estonia

Estimated number of species of: Bees **Butterflies** **Hoverflies**	238 104 224
Red List[1] for: Bees **Butterflies** **Hoverflies**	Yes In progress No
Number of monitoring sites needed:	28
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€4,000 €136,000 €197,000

Finland

Estimated number of species of: Bees **Butterflies** **Hoverflies**	246 110 362
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	150
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€21,000 €1,190,000 €127,000

France



Estimated number of species of: Bees **Butterflies** **Hoverflies**	951 255 563
Red List for: Bees **Butterflies** **Hoverflies**	Planned Yes No
Number of monitoring sites needed:	238
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€32,000 €1,794,000 €400,000

Germany

Estimated number of species of: Bees **Butterflies** **Hoverflies**	583 178 463
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes Yes
Number of monitoring sites needed:	159
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€22,000 €1,118,000 €117,000

Greece

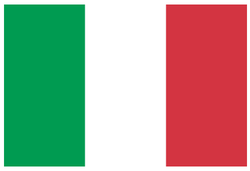
Estimated number of species of: Bees **Butterflies** **Hoverflies**	1,171 235 418
Red List for: Bees **Butterflies** **Hoverflies**	No Yes No
Number of monitoring sites needed:	65
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€9,000 €290,000 €368,000

Hungary

Estimated number of species of: Bees **Butterflies** **Hoverflies**	715 156 388
Red List for: Bees **Butterflies** **Hoverflies**	Yes In progress No
Number of monitoring sites needed:	48
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€6,000 €172,000 €361,000

Ireland

Estimated number of species of: Bees **Butterflies** **Hoverflies**	99 35 180
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	39
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€5,000 €260,000 €159,000

Italy	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	1,017 272 536
Red List for: Bees **Butterflies** **Hoverflies**	In progress Yes No
Number of monitoring sites needed:	136
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€18,000 €873,000 €326,000

Latvia	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	288 188 302
Number of monitoring sites needed:	37
Red List for: Bees **Butterflies** **Hoverflies**	Yes No No
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€5,000 €161,000 €250,000

Lithuania	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	330 120 269
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	37
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€5,000 €190,000 €252,000

Luxembourg	
Estimated number of species of: Bees Butterflies Hoverflies	338 88 178
Red List for: Bees Butterflies Hoverflies	No Yes No
Number of monitoring sites needed:	12
Estimated costs for: Scheme establishment Annual implementation Capacity building	€2,000 €100,000 €222,000

Malta	
Estimated number of species of: Bees Butterflies Hoverflies	99 23 46
Red List for: Bees Butterflies Hoverflies	No No No
Number of monitoring sites needed:	10
Estimated costs for: Scheme establishment Annual implementation Capacity building	€1,000 €53,000 €265,000

Netherlands	
Estimated number of species of: Bees Butterflies Hoverflies	363 77 328
Red List for: Bees Butterflies Hoverflies	Yes Yes No
Number of monitoring sites needed:	26
Estimated costs for: Scheme establishment Annual implementation Capacity building	€4,000 €219,000 €182,000

Poland	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	512 154 411
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	141
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€19,000 €429,000 €290,000

Portugal	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	699 133 195
Red List for: Bees **Butterflies** **Hoverflies**	No No No
Number of monitoring sites needed:	46
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€6,000 €245,000 €272,000

Romania	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	721 193 481
Red List for: Bees **Butterflies** **Hoverflies**	In progress Yes No
Number of monitoring sites needed:	110
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€15,000 €312,000 €422,000

Slovakia	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	635 172 384
Red List for: Bees **Butterflies** **Hoverflies**	Yes In progress No
Number of monitoring sites needed:	30
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€4,000 €110,000 €329,000

Slovenia	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	583 179 309
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	19
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€3,000 €96,000 €344,000

Spain	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	1,125 233 417
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	217
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€29,000 €1,303,000 €263,000

Sweden	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	294 111 393
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes No
Number of monitoring sites needed:	197
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€29,000 €1,555,000 €172,000

United Kingdom	
Estimated number of species of: Bees **Butterflies** **Hoverflies**	271 63 284
Red List for: Bees **Butterflies** **Hoverflies**	Yes Yes Yes
Number of monitoring sites needed:	114
Estimated costs for: Scheme establishment **Annual implementation** **Capacity building**	€15,000 €1,000,000 €123,000

Notes on summaries

The number species for each taxa included in the tables is an estimate, since numbers reported may vary depending upon the source.

Bees: we used a single source, Discoverlife[1], which is regularly updated, although it sometimes returns slightly higher numbers of species than reported by other sources, and the figure used here has been updated by national experts as needed.

Butterflies: the number of species includes those only resident and regular migrants according to Maes et al. 2019.

Hoverflies: the numbers were extracted from a wide range of primary publications listed below.

The **number of monitoring sites needed** is the minimum number required in a given Member State in order to be able to detect a 30-50% decline in the EU over 10 years as part of the Minimum Viable Scheme (section 5.1).

Cost estimates are those calculated in section 5.4 of the main report. National costs are split into **establishment costs** (start-up costs) and **annual implementation costs** for actual monitoring. Start-up costs, the costs of long-lasting material components (e.g. nets and pan-traps). Annual monitoring costs are the full costs of annual wages for staff, consumable materials, fuel, travel, accommodation, postage of samples, sample identification and training events.

Capacity building cost estimates per country are based on the data gaps for each of the three pollinator groups identified in Chapter 7, and the associated costs within that chapter.

Checklists: €600,000 costed at an EU level (section 7.2.6.).

Field Guides: costed for Taxa that do not have them multiplied by the number of official languages (section 7.2.3.). In addition, European-wide field guides would ultimately need to be developed, costed at €300,000 (hoverflies) and €400,000 (bees) respectively (section 7.2.2.).

Online ID: assume a single EU-wide system: online platform @ €60,000 start-up (section 7.2.7.), plus mobile app. @ €80,000/species group (section 7.2.8.).

Atlas: assume a single EU-wide system at the costs indicated: €20,000 start-up costs for status reports and €20,000 for establishing a database, building on infrastructure (section 7.2.5.).

Online records: these are assumed to cover €400,000 for digitisation of type material and other digitisation projects at an EU level (section 7.2.9.).

Handbook: not costed but would be incorporated within other aspects of capacity building.

1 https://www.discoverlife.org/mp/20q?guide=Apoidea_species&flags=HAS:

National Red List: Costed at €50,000 per taxa (section 7.2.10).

Internet Fora: these are not explicitly costed and can be as simple as a group on a free platform such as Facebook.

DNA barcoding: DNA sequencing for 50 individuals per species (25M, 25F); this sequencing costs €1.85/specimen materials, €877 annual primers and 6% local staff (technician) time (based on figures from Breeze et al 2020, €2.30/specimen + €1,092 primers), plus 20% for overheads; plus €2,000 to establish a baseline and ~€1M for an EU-level database (section 7.2.4.).

Core Capacity Building: costed at €90,000 based on the sum of costs of acquisition of key items (€40,000) and a national reference collection (€50,000) from section 7.2.1.

References

Ball SG & Morris RKA 2014. A review of the scarce and threatened flies of Great Britain. Part 6: Syrphidae. *Species Status*, 9: 1–130.

Breeze TD, Bailey AP, Balcombe KG, Brereton T, Comont R, Edwards M, Garratt MP, Harvey M, Hawes C, Isaac N, Jitlal M, Jones C, Kunin WE, Lee P, Morris RKA, Musgrove A, O'Connor RS, Peyton J, Potts SG, Roberts SPM, Roy DB, Roy HE, Tang CQ, Vanbergen AJ and Carvell C (2020). Pollinator Monitoring More than Pays for Itself. Journal of Applied Ecology in press

Burgio G, Sommaggio D & Birtele D 2015. I Sirfidi (Ditteri): biodiversità econservazione. iSPRA, Manuali e Linee Guida 128/2015, 182 pp.

Bygebjerg R 2019. Svirrefluer. I Moeslund, J.E. m.fl. (Eds.) Den danske Rødliste 2019. Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi. Available at: redlist.au.dk.

Ebejer MJ 1995. The hoverflies of Malta (Diptera: Syrphidae), new records and corrections. *The Central Mediterranean Naturalist*, 2 (3): 81–85.

Farkac J, Král D & Škorpík M (Eds.) 2005. *Cervený seznam ohrožených druhu Ceské republiky. Bezobratlí. List of threatened species in the Czech Republic*. Invertebrates. – Agentura ochrany prírody a krajiny CR, Praha, 760 pp.

Gardenfors U (Eds.) 2000. Rodlistade-arter i Sverige 2000 (The 2000 Red List of Swedish Species). *ArtDatabanken, Swedish University of Agricultural Science, Uppsala*.

Haarto A & Kerppola S 2014. Checklist of the family Syrphidae (Diptera) of Finland. *In*: Kahanpää, J. & Salmela, J. (Eds.) Checklist of the Diptera of Finland. *ZooKeys*, 441: 233–249. doi: 10.3897/zookeys.441.7251

Heimburg H 2018. Checkliste der Schwebfliegen (Diptera: Syrphidae) Österreichs. Karl-Franzens-Universität Graz. Masterarbeit.

Hyvärinen E, Juslén A, Kemppainen E, Uddström A & Liukko U.-M. (Eds.) 2019. The 2019 Red List of Finnish Species. Ympäristöministeriö & Suomen ympäristökeskus. Helsinki. 704 pp.

Jeličić Ž, Vujić A, Vignjević G, Merdić E. 2010. Hoverflies (Diptera: Syrphidae) of Kopački rit Nature Park, NE Croatia. *Entomologia Croatica*, 14 (3–4): 7–18.

Karpa A 2008. Catalogue of Latvian flies (Diptera: Brachycera). *Latvijas entomologs*, 46: 4–43.

Kuznetzov, S. Yu. 1993. A checklist of Latvian, Lithuanian and Estonian hoverflies (Diptera, Syrphidae). *Dipterological Research*, 4 (1–2): 35–47.

Likov L 2018. Fauna of hoverflies (Diptera: Syrphidae) of Greece. University of Novi Sad, Faculty of Sciences. PhD thesis.

Lutovinovas E 2006. New and rare for Lithuania hoverfly (Diptera: Syrphidae) species recorded in recent years. *New and rare for Lithuania insect species*, 17: 66–70.

Maes D, Verovnik R, Wiemers M, Brosens D, Beshkov S, Bonelli S, Buszko J, Cantú-Salazar L, Cassar L.-F, Collins S, Dinca V, Djuric M, Dusej G, Elven H, Franeta F, Garcia-Pereira P, Geryak Y, Goffart P, Gór Á, Hiermann U, Höttinger H, Huemer P, Jakšic P, John

E, Kalivoda H, Kati V, Kirkland P, Komac B, Korösi Á, Kulak A, Kuussaari M, L'Hoste L, Lelo S, Mestdagh X, Micevski N, Mihoci I, Mihut S, Monasterio-León Y, Morgun DV, Munguira ML, Murray T, Stadel Nielsen P, Ólafsson E, Õunap E, Pamperis L, Pavlícko A, Pettersson LB, Popov S, Popovic M, Pöyry J, Prentice M, Ryrholm N, Šašic M, Savenkov N, Settele J, Sielezniew M, Sinev S, Stefanescu C, Švitra G, Tammaru T, Tiitsaar A, Tzirkalli E, Tzortzakaki O, van Swaay CAM, Lykke Viborg A, Wynhoff I, Zografou K, Warren MS. 2019: Integrating national Red Lists for prioritising conservation actions for European butterflies. - Journal of Insect Conservation 23: 301-330

Mazanek L 2009. Checklist of Diptera of the Czech Republic and Slovakia electronic version 2. Available at: http://www.edvis.sk/diptera2009/

Mazanek L 2009. Checklist of Diptera of the Czech Republic and Slovakia electronic version 2. Available at: http://www.edvis.sk/diptera2009/

Meutter F 2011. An annotated catalogue of the hoverflies (Diptera: Syrphidae) of Belgium. *Studia dipterologica*, 18 (1/2): 55–75.

Mielczarek L 2009. List of species Syrphidae of Poland (Diptera, Syrphidae). Available at: http://syrphidae.insects.pl/checklist.php?lang=en

Red list of the Spanish invertebrates. Available at: https://cibio.ua.es/lrie/tabla.html

Reemer M, Renema W, Van Steenis W, Zeegers T, Barendregt A, Smit JT, van Veen M, van Steenis J & Van der Leij LJJM 2009. De Nederlandse Zweefvliegen (Diptera: Syrphidae). Nederlandse Fauna 8. *Nationaal Natuurhistorisch Museum Naturalis, Leiden*. 449 pp.

Ricarte A & Marcos-Garcia MA 2017. A checklist of the Syrphidae (Diptera) of Spain, Andorra and Gibraltar. *Zootaxa*, 4216 (5): 401–440.

Speight MCD 2008. Database of Irish Syrphidae (Diptera). *Irish Wildlife Manuals,* No. 36. National Parks and Wildlife Service, Department of Environment, Heritage and Local Government, Dublin, Ireland.

Speight MCD, Sarthou JP, Vanappelghem C & Sarthou V 2018. Maps of the departmental distribution of syrphid species in France/Cartes de distribution departmentale des syrphes de France (Diptera: Syrphidae). Syrph the Net, the database on European Syrphidae (Diptera). Syrph the Net publication, Dublin. Vol. 100, 80 pp.

Ssymank A, Doczkal D, Rennwald K & Dziock F 2011. Rote Liste und Gesamtartenliste der Schwebfliegen (Diptera: Syrphidae) Deutschlands. *In*: Binot-Hafke M, Balzer S, Becker N, Gruttke H, Haupt H, Hofbauer N, Ludwig G, Matzke-Hajek G & Strauch M. (Eds.): Rote Liste gefährdeter Tiere, Pflanzen und Pilze Deutschlands. Band 3: Wirbellose Tiere (Teil 1). Münster (Landwirtschaftsverlag). *Naturschutz und Biologische Vielfalt*, 70 (3): 13-83, available at: https://www.allearter-databasen.dk/ Petersen, F.T. & Meier, R. 2001. A preliminary list of the Diptera of Denmark. *Steenstrupia*, 26 (2): 119–276.

Stanescu C & Parvu C 2005. Syrphids (Diptera: Syrphidae) of Romania. Checklist, phenology, distribution. *Trav. Mus. Nat. His. Nat. Gr. Antipa*, 48: 177–202.

Tóth S 2011. Hoverfly fauna of Hungary (Diptera: Syrphidae). *e-Acta Naturalia Pannonica* (Supl. 1), 5–408.

Tóth S 2014. Additional data to the Hoverfly fauna of South West Bulgaria (Diptera: Syrphidae). *Natura Somogyiensis*, 197–220.

van Eck A, 2016. Hoverflies (Diptera, Syrphidae) new to the fauna of mainland Portugal, with an updated hoverfly checklist. *Boletín de la Sociedad Entomológica Aragonesa (SEA)*, 59: 187–203.

van Steenis J Swedish hoverfly records (Diptera: Syrphidae). *Entomologisk Tidskrift*, 132 (3): 187–193.

van Steenis J, van Zuijen MP, van Steenis W, Makris C, van Eck A & Mengual X. 2019. Hoverflies (Diptera: Syrphidae) of Cyprus: results from a collecting trip in October 2017. *Bonn zoological Bulletin,* 68 (1): 125–146.

van Steenis W 2006. Hoverflies new to Luxembourg (Insecta, Diptera, Syrphidae). *Bull. Soc. Nat. luxemb.,* 106: 101–104.

van Steenis W, de Groot M, & van Steenis J 2013. New data on the hoverflies (Diptera: Syrphidae) of Slovenia. *Acta Entomologica Slovenica*, 21 (2): 131–162.

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),
- at the following standard number: +32 22999696, or
- by electronic mail via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

KJ-NA-30416-EN-N

The European Commission's science and knowledge service
Joint Research Centre

JRC Mission
As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office of the European Union

doi:10.2760/881843
ISBN 978-92-76-23859-1