Meeting report

Can we harmonize the monitoring of plants and pollinators?

Meeting report on the symposium 'New solutions to monitor plants, pollinators and their interactions in a changing world', held at Collège de France and Muséum national d'Histoire naturelle, Paris, France, 23–24 May 2024

Pollution, climate change, and shrinking habitats are driving major changes in flowering plant and pollinator populations. These include shifts in local abundance, population extirpations, range shifts, altered community composition, and reshuffled interactions. To date, evidence for these changes mostly reflect opportunistic efforts to collect occurrence data to document distributions. Coarse-scale perspectives on biodiversity change can be invaluable, especially when threats to rare habitats are widely distributed, but many changes occur slowly (decades) at such scales. Opportunistic occurrence data are therefore generally less useful for detecting short-term trends and monitoring the effectiveness of conservation policies. They are also typically biased for large-scale surveillance monitoring (Boyd *et al.*, 2022) and rarely encompass both plants and pollinators, limiting our ability to estimate broad and fine-scale trends in populations and plant–pollinator interactions. Ecologists often prefer using plot-based methods for systematic surveys and monitoring, as these provide quantitative data on abundance and distributions. Resurveying such plots adds a time dimension, greatly enriching our understanding of how species abundances and distributions shift in response to drivers of global change. Monitoring and resurvey data remain scarce, leaving pictures of ecological conditions and change uncertain. Except for Switzerland and the UK, countries are slow to support systematic programs to monitor plants and pollinators.

The 23–24 May Paris symposium on 'New solutions to monitor plants, pollinators and their interactions in a changing world' brought scientists together to assess the state of plant and pollinator monitoring schemes in Europe and to ponder how these might be improved, extended, and coordinated (https://www.college-de-france.fr/fr/agenda/colloque/nouvelles-approches-pour-le-suivi-des-plantes-des-pollinisateurs-et-de-leurs-interactions-dans-un). This group met to review existing schemes, compare the trends and indicators they produce, and outline future needs for research and policy. These needs include expanding the number of plots, species and habitats monitored, the different methods (e.g. by citizen scientists) and how frequently they are surveyed; how to identify and locate plants and insects quickly and reliably (including new technologies); how best to coordinate plant and pollinator sampling; and statistical tools to integrate heterogeneous data and infer causal relationships.

What drives plant and pollinator changes across Europe and North America?

Efforts to monitor plants include six schemes launched between 2001 and 2017 that range from regional to national in scope (Fig. 1), plus two international resurvey initiatives with the earliest observations in 1927. These programs share the following: (1) a plot-based design focused on vascular plants; (2) regular resurveys of these plots (at variable frequencies); (3) standardized protocols for collecting data on abundance or frequency; and (4) success in documenting systematic changes in plant abundances, diversity, and/or community composition. Many plant species show declining abundance (e.g. National Plant Monitoring Scheme (NPMS): unpublished; ReSurveyEurope: Jandt *et al.*, 2022), but threatened plants in Northeastern Spain show high stability (Garcia *et al.*, 2021). Population increases and declines are associated with climate change (especially 'thermophilization' – Vigie-flore: Martin *et al.*, 2019; forestREplot: Zellweger *et al.*, 2020), eutrophication (Biodiversity Monitoring Switzerland (BDM): Roth *et al.*, 2013; North America: Clark *et al.*, 2019), and biotic homogenization (BDM: Buehler & Roth, 2011). Plant–animal interactions also alter plant communities. The impacts of herbivory have long been documented; declines in animal-pollinated plants are another apparently widespread, but more recently observed, phenomenon (North America: Wiegmann & Waller, 2006; Novana: Ehlers *et al.*, 2021; BDM: Abrahamczyk *et al.*, 2022; Vigie-flore: unpublished).

Monitoring plant/pollinator communities: current schemes and the way forward

Although the symposium identified some common changes in diversity across Europe, differences also exist among countries that deserve investigation. Some of them may reflect the lack of a common monitoring system across Europe, as well as other intrinsic biases in design or implementation (e.g. nonrandom distributions of volunteers in space and over time). To supplement our symposium, we organized a survey to collect additional data on European plant monitoring schemes (https://mnhncesco.limesurvey.net/985853?lang=en). This was intended to facilitate a more complete comparison of how schemes vary in spatial, temporal, and ecological coverage and the use of volunteer vs professional staff. The resulting review should highlight conspicuous gaps in monitoring and suggest guidelines to improve existing and proposed monitoring schemes. These guidelines will likely

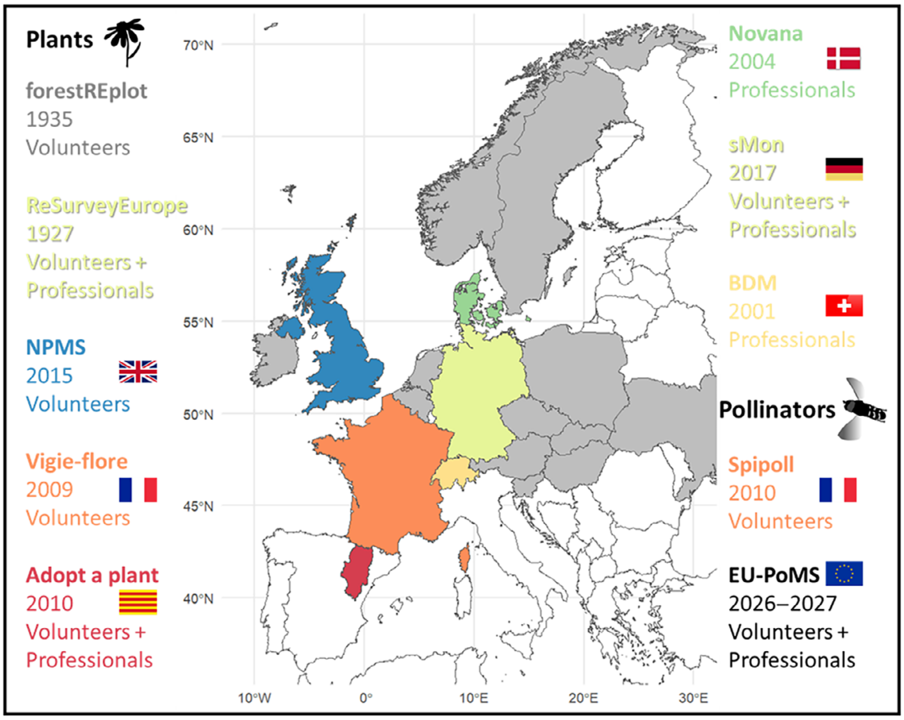

Fig. 1 Existing or future monitoring schemes presented during the symposium: spatial distribution, launch year, and type of participants. All highlighted countries, apart from Spain and Denmark, are also part of the forestREplot network which also covers the United States and Canada. BDM, Biodiversity Monitoring Switzerland; EU-PoMS, EU Pollinator Monitoring Scheme; NPMS, National Plant Monitoring Scheme; Spipoll, Suivi Photographique des Insectes Pollinisateurs. ReSurveyEurope is a database that covers most of Europe, but only results from Germany were presented during the symposium. 'Professional' participants sometimes include researchers.

include needs for geographical representativeness, stratification in sampling, ways to include rare species or habitats, and statistical methods to characterize change.

Monitoring wild pollinators is even less frequent across most of Europe, reflecting in part their impressive diversity (2138 species of bees, 496 butterflies, 913 hoverflies, plus thousands of uncounted moths, flies, wasps, and beetles). Relatively few specialists exist for many of these groups, and entomological citizen science efforts are more difficult or impossible. Monitoring schemes exist in a few countries (e.g. the UK), but overall, we have few data on abundance except for butterflies. We thus lack trend data for most pollinators and pollination services across the EU, especially in southern and eastern Europe where basic knowledge is lacking even for well-studied groups. However, the symposium was encouraged to learn that a standardized EU pollinator monitoring scheme (EU-PoMS) is under development to overcome current knowledge gaps. The EU's new (2024) Nature Restoration Law may provide an opportunity to implement EU-PoMS.

Assuming adequate plant and pollinator monitoring can be implemented, it will still be necessary to link these efforts to document shifts in plant–pollinator interactions. Coordinated joint plant–pollinator monitoring schemes would help us understand how plants affect pollinators and vice versa. In this regard, it was encouraging to learn of the 'Spipoll' program that seeks to document plant–pollinator interactions using large numbers of volunteers' photographs collected according to a standardized protocol. Spipoll data have already been used to characterize how specialized pollinators tend to avoid urban areas (Deguines *et al.*, 2016). Additional programs designed to monitor both plant and insect populations at shared locations would further enhance our ability to detect changes in plant–pollinator interactions.

Joint analysis of heterogenous schemes: need for tailored statistical tools

The diversity of goals, methodologies, and data structures among the reviewed programs makes it clear that it will be difficult or impossible to standardize data collection procedures across countries and monitoring schemes. Instead, we might usefully seek to construct a modeling framework to extract similar key information from different data types. In particular, it may be possible to link programs using different types of data at different frequencies and spatial scales using rarefaction and latent variables to capture changes over time and space. Similar hierarchical models have been used elsewhere to extract information from different data types (NPMS: Pescott *et al.*, 2019). For these efforts to succeed, we need to focus on a few key concepts, such as changes in abundance over time, to investigate the combined datasets.

Technological innovations and data integration

Visual analysis techniques to detect and identify species have improved significantly in recent years. They may enable us to improve monitoring programs by automating some aspects of species identification, data entry, and validation. Advancing sensor and analysis (AI) technologies have reduced costs while enhancing capabilities, allowing these technologies to be applied to smaller and more active animals (e.g. pollinators) and diverse small herbaceous species embedded within other vegetation. Photographic traps could be used to detect and monitor insects at flowers and quantify interactions. So far, efforts to identify plant species have mainly used close-up images of flowers and/or leaves. Newer efforts use massive visual learning data derived from citizen science

Fig. 2 High-resolution plot image acquired by a citizen scientist with a standard smartphone. Advances in sensor and analysis (AI) and computer vision could eventually enable automatic identification of the species present in such images as well as their percent of ground cover. This could considerably reduce the cost (in terms of human and financial resources) of vegetation plot monitoring schemes. Picture by Mathias Chouet (CC-BY-SA).

platforms such as iNaturalist (https://www.inaturalist.org) or Pl@ntNet to continually improve accuracy and reliability (Joly *et al*., 2016). New deep-learning models (e.g. vision transformers) allow new types of analysis (Elvekjaer *et al*., 2024). Field workers may soon take high-resolution quadrat images (Fig. 2) for subsequent analysis by self-supervised learning models to generate data on species frequency and cover. Eventually, autonomous drones or ground vehicles equipped with cameras might lower costs enough to allow regular systematic monitoring of large areas, greatly enhancing our ability to monitor ecological change. However, care must be taken to keep botanists and citizens in the field, to maintain their knowledge and connection with nature, as well as to collect reference data that are necessary to validate new technologies.

Policy and international collaboration: implications for conservation

Structured monitoring schemes, especially when linked together, can generate sensitive indicators to detect changes in abundance and early-warning signals of impending extirpations. When these efforts are consistent, extensive, and extended over time, they also provide opportunities to test which environmental factors most likely drive these changes (e.g. by using 'natural experiments' that exploit spatial variation in environmental conditions). Consistent and continued monitoring programs are also essential to assess whether public policies and programs are meeting their goals. The EU's new Nature Restoration Law aims to restore at least 20% of the EU's land and sea areas by 2030 and all ecosystems needing restoration by 2050. Harmonized plant monitoring initiatives across Europe along the lines of EU-PoMS would provide a key tool for assessing its success. Coordinating these programs at the international scale will facilitate comparisons among temperate regions, increasing our ability to describe changes and infer causes. It would also serve as a useful model for monitoring ecological change in other biogeographical regions, including the tropics. The Paris symposium provided a first step in this direction and clears some of the weeds from the path.

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