SafeNet: A European database of plant-pollinator interactions

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Abstract

Motivation: Pollinators play a crucial role in maintaining Earth's terrestrial biodiversity and human food production by mediating sexual reproduction for most flowering plants. However, their diversity and role as pollinators are increasingly compromised by rapid human-induced environmental changes. One of the major challenges for pollinator conservation, is the lack of robust generalisable data across space and time to comprehend the conservation status and population trends among different pollinator species. Here, we present the SafeNet database, a fully reproducible European-level database containing harmonized taxonomic data on plant-pollinator interactions referenced in both space and time. This database offers an open workflow that allows researchers to track decisions and edit them according to their preferences, while also providing other ecological variables of interest. We hope this database can help researchers to: 1) identify taxonomic, ecological and geographical gaps of knowledge on plant-pollinator interactions; and 2) explore the impacts of global change to guide future conservation planning for both plant and pollinator species.

Main Types of Variables Included: SafeNet contains 1,150,097 interactions between plants and pollinators from 51 different studies distributed across 17 European countries. In addition, information about sampling methodology, habitat type, bio-climatic region and further taxonomic rank information for both plant and pollinator species are also provided.

Spatial location and grain: The database contains 1,146 different sampling locations from natural and anthropogenic habitats that fall in 5 different bio-climatic regions. All records are geo-referenced and presented in the World Geodetic System 1984 (WGS84).

Time period and grain: Species interaction data was recorded between 2004 and 2021. All records are time-referenced and most of the studies documented interactions in a single flowering season (68.63%).

Major taxa and level of measurement: The database contains interaction data at the species level for 94.76% of the records, including a total of 1,353 plant and 2,065 pollinator species. The database covers 5.33% of the European species of flowering plants. The main focus of this database are insect pollinators and accounts for 33.77% of bees, 39.72% of butterflies and 33.19% of syrphids species at the European level.

Software format: The database was built with R software and is stored as ".rds" and ".csv" formats. The construction of the database is fully reproducible and can be accessed at the following PERMANENT LINKS.

KEYWORDS

plant-pollinator interactions, flowering plants, Angiosperms, pollinators, Hymenoptera, Diptera, Lepidoptera, Coleoptera, Europe

Introduction

The interaction between plants and pollinators is one of the most well-documented mutualisms on Earth. Plant-pollinator interactions involve a great diversity of species, largely attributed to their coevolutive history (Ollerton 2017), and are critically important for terrestrial biodiversity and the human economy. The synergistic effects of climate change with other global change pressures are threatening worldwide biodiversity (Sala et al. 2000; Bellard et al. 2014), including plant and pollinator species as well as their interactions (González-Varo et al. 2013; Settele, Bishop, and Potts 2016; Eichenberg et al. 2021). Under this scenario, the increasing availability of biodiversity data plays a major role in our ecological understanding of species and guiding conservation planning (Heberling et al. 2021). However, our knowledge of plant and pollinator species and their network of interactions still exhibits major temporal, spatial and taxonomic biases (Archer et al. 2014; Troia and McManamay 2016; Poisot et al. 2021; Marshall et al. 2024), limiting our ability to effectively protect their biodiversity.

Europe is one of the continents with a larger amount of available biodiversity data (Proença et al. 2017), yet still exhibits major gaps (Wetzel et al. 2018; Bennett et al. 2018). While species checklists need to be treated carefully, especially at a macro-ecological scale (Grenié et al. 2023), the growing number of European plant and pollinator checklists along with occurrence data, is setting a foundation for the conservation of its flora and their pollinators. However, species richness is just one component of biodiversity and documenting the interaction between plants and pollinators is essential for understanding the fate of the species within an ecosystem (Jordano 2016). Numerous works have studied plant-pollinator interactions in the last decades, originating thousands of plant-pollinator interaction networks worldwide. Several initiatives have tried to integrate plant-pollinator interaction data into databases such as *Mangal* (Poisot et al. 2016) or *GloBI* (Poelen, Simons, and Mungall 2014), resulting in numerous large scale comparative analyses that enhanced our understanding of the ecology of plants and pollinators (e.g., European wild bee data trends; Marshall et al. 2024). Despite all these resources, Europe lacks accessible harmonized plant-pollinator interaction data that allow researchers to evaluate the state of the art of plant-pollinator interactions at European level, which will guide research efforts, conservation planning and will set a foundation for future global change research.

The interactions between different plant and pollinator species within a community form complex networks. Macro-ecological analyses of the topology of these networks have revealed common properties across them, such as truncated power-law degree distributions (Jordano 1987) or nestedness (Bascompte et al. 2003), and has added relevant information of their interaction ecology of plant-pollinator networks across geographic regions (Olesen and Jordano 2002; Traveset et al. 2016) and environmental gradients (Ramos-Jiliberto et al. 2010; Rech et al. 2016; Saunders et al. 2023). Although macro-ecological approaches make significant contributions to knowledge, they tend to be rare, and are strongly influenced by the spatio-temporal availability and nature of the data (Burkle and Alarcón 2011; Trøjelsgaard and Olesen 2013). For instance, plant-pollinator studies tend to differ in sampling effort and methodology which can impact the structure of the resulting plant-pollinator networks (Gibson et al. 2011; Jordano 2016). Further, despite little sampling effort could capture most of the relevant functional species (Hegland et al. 2010), most plant-pollinator networks have unobserved interactions because undersampling (Olesen et al. 2011; Chacoff et al. 2012). Thus, the lack of strong spatio-temporal coverage along the current intrinsic limitations of sampling plant-pollinator networks, highlight the need of keep gathering and integrating informative species interaction data to properly unravel the different ecological processes at large scales.

Here, we present the SafeNet database, an acronym derived from the European project Safeguard and plant-pollinator networks, which contains harmonized informative interaction data of plants and pollinators at European level. The primary focus of the pollinator taxonomic groups is on the main orders of entomofauna that visit and pollinate flowering plants in Europe. These include insect species from the orders Hymenoptera, Diptera, Lepidoptera, and Coleoptera (Potts et al. 2015), which comprise almost the totality of recorded interactions in the SafeNet database (99.88%). SafeNet aims to cover a wide range of taxonomic groups and habitats while also provides other variables of interest that allow to better control for the ecological context and sampling methods. In addition, SafeNet offers a transparent and accessible workflow of its data management and species harmonization that allow to being reused and keep building on it over time. We expect that this database will help to evaluate macro-ecological processes and current gaps of plant-pollinator interactions at European level.

Methods

Data acquisition

This database is the result of one of the working packages of the European project Safeguard. The SafeNet database includes published and unpublished studies compiled initially by a wide number of researchers and institutions within the European continent. Data acquisition followed a non-systematic approach. First, data was directly asked to members of the Safeguard project and then, the request was extended to data owners outside of the project. These other studies were identified by direct communication with other colleagues and by directly searching studies on Google Scholar of under-represented regions of countries within the database. To keep high quality standards that will allow robust future ecological research, we only included: 1) studies that contained time- and geo-referenced records of plant-pollinator interactions; 2) studies with phyto-centric plant-pollinator networks with quantitative visitation data. The database contains 51 independent published and unpublished studies conducted during the time period 2004 - 2021 on 17 different countries (**Figure 1a**).

Dataset description

SafeNet includes a total of 1,150,097 distinct interactions, considering interaction as the contact of a given pollinator to the reproductive structure of a particular plant, from 2,065 pollinator and 1,353 plant species. The majority of plant and pollinator species tend to be regionally specific, with only a minor portion of them being shared across a broad range of studies (**Figure 1b**). These different studies differ in sampling effort and methodology, although most studies took place within a single flowering season (68.63%), sampled a given location an average of 7.54 days, and documented interactions mostly by using transects as sampling method (62.75%).

Define study area//Data structure? TABLE? Describe cols?

Taxonomic harmonization

All plant and pollinator species names were checked and standardized according to large scale taxonomic databases. To ensure reproducibility of the workflow, we have conducted this harmonization in R with **rgbif** (Chamberlain, Oldoni, and Waller 2022) as pivotal package to check for species names and retrieve further taxonomic information (i.e., phylum, order, family and genus) from the Global Biodiversity Information Facility (GBIF). The protocol for plants and pollinators is similar but slightly different given the availability of the different taxonomic resources. For transparency, we have included in the database the old species name, the new assigned name, and, if name of the species is uncertain (e.g., species complex or species alike).

For plants: (i) we initially verify exact matches with the GBIF species checklist; (ii) select unmatched cases and fix orthographic errors; (iii) retrieve again taxonomic information for those unmatched cases, evaluate accuracy of fuzzing matching and programmatically fix records that are still not found; (iv) finally, we used the World Flora Taxonomic Backbone (Govaerts et al. 2021; WFO, July 7, 2022) as the ultimate filter for taxonomic information as we used it to calculate the plant taxonomic coverage of our database.

For pollinators: (i) we first created a checklist of species names for the most representative pollinator groups at European level by combining the recently published checklists of bees (Ghisbain et al. 2023), syrphids (Kočić et al. 2023) and butterflies (Wiemers et al. 2018); (ii) then, we compared pollinator species names against the checklist and recovered some unmatched cases with restrictive fuzzy matching by using **stringdist** package (Van der Loo et al. 2014); (iii) we programmatically fixed unmatched records when necessary and retrieved the taxonomic information for all species from GBIF; (iv) we fixed the non-found cases in the GBIF checklist and made sure that all species names from bees, syrphids and butterflies were named according to their respective species checklists.

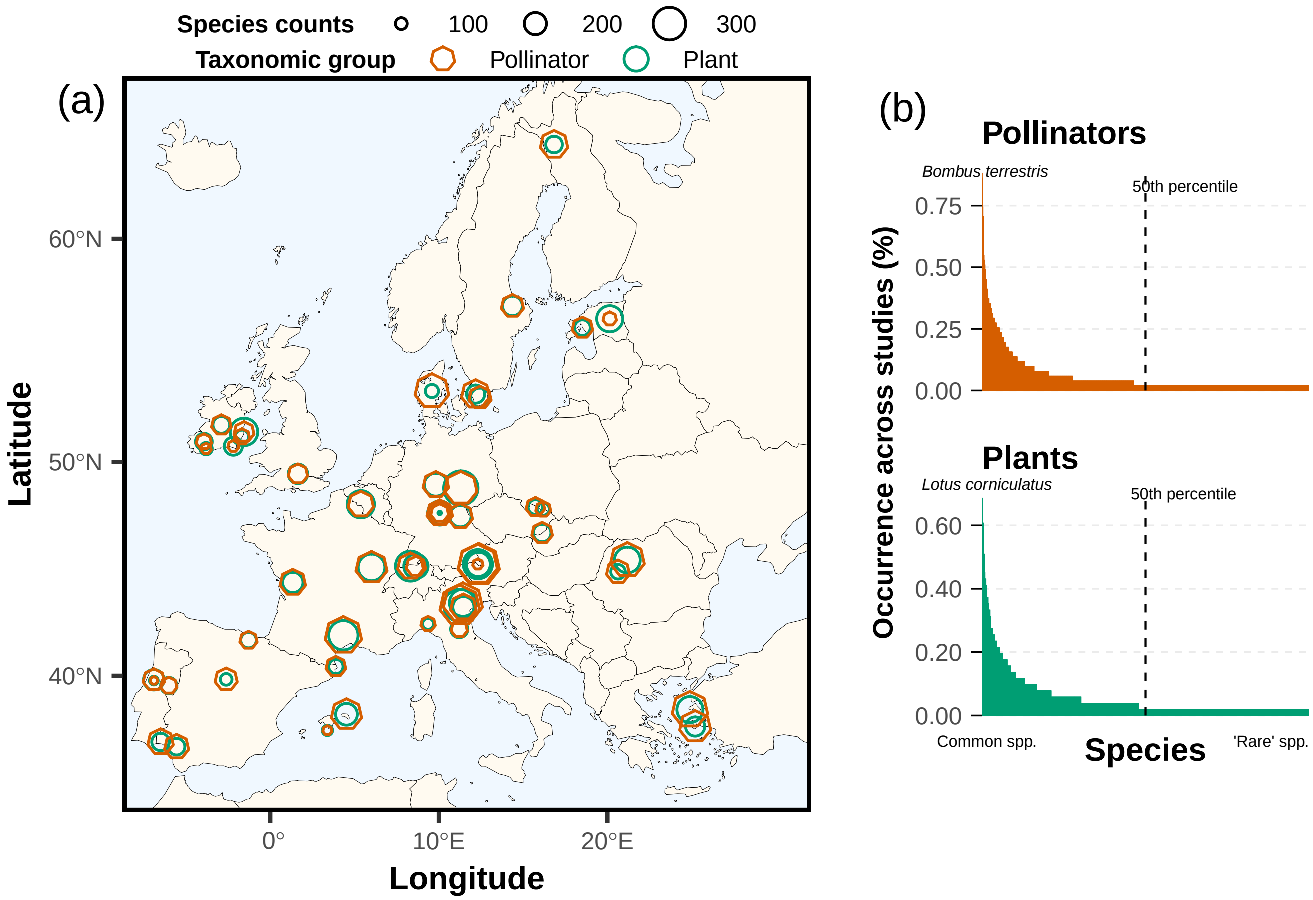

Figure 1. (**a**) Approximate locations of the studies of the SafeNet database showing the total number of pollinator (i.e., orange heptagon) and plant (i.e., green circles) species per study. The sizes of these shapes are proportional to the respective species counts. For visualization purposes, we have focused only on the European region with studies and selected a single location per study. (**b**) Percentage of shared occurrences of pollinators and plants across studies. Species on the left are highly shared across studies, while species on the right are found only in a few or a single study. As a reference, we have indicated the 50th percentile with a black dashed vertical line.

Taxonomic coverage

To assess the completeness of plant and pollinator species in the SafeNet database at European level, we used the aforementioned checklists for plants and pollinators. Specifically for plants, we refined the checklist to include only European flowering plants and excluded taxonomic groups not associated with biotic pollination. We did this by first excluding the families considered to have exclusively a wind pollination mode (see Culley, Weller, and Sakai 2002), and then by filtering out the genera with wind or non-biotic pollination from families that exhibit both biotic and non-biotic pollination modes. Additionally, we manually included some exotic species and added unresolved species names that were not present in the accepted names of the checklist at the current version of usage. For pollinators, we compared only the taxonomic coverage of bees, syrphids and butterflies by using their species checklists at European level.

Habitat type and bioclimatic region

The different sites per study were classified with a habitat type by the authors. As these habitats are not standardized across studies, they were standardized with the additional help of land cover information and visual checks on current satellite imagery. For each georeferenced site, the land cover information was extracted from Corine Land Cover (CLC, version 2018) with the help of the Terra package (Hijmans et al. 2022). Based on the habitat classification from the authors and the CLC classification, we created habitat categories that intend to summarize the diversity of habitats in the SafeNet database (see habitat type definition in supplementary material). These categories allow a quick comparison and understanding of the habitat types from the database. However, we advise authors to revise this classification if they intend to rely on this field for their analyses as this is a non-fully objective process. Moreover, Europe is characterized by a great variety of environmental conditions that harbor different biota. Thus, to allow authors to explore set of studies that share similar environmental conditions and species, we assigned to each site a biogeographical region. The biogeographical regions were downloaded from the European Environment Agency (version 2016) and were matched to the different sites with the help of a spatial joint from the **sf** package (Pebesma et al. 2018).

Results

PART A

Provide number of species per taxonomic group and number of interactions Something always of interest: provide % of interactions of *Apis mellifera*?

PART B

Explain habitat and bioregion

FIGURE 5? CLIFFHANGER OF NETWORK METRICS

Taxonomy and taxonomic coverage

Habitat type and bioclimatic region

Discussion

Geographic and taxonomic biases!

Contextualise European diversity of plant and pollinator species with global biodiveristy

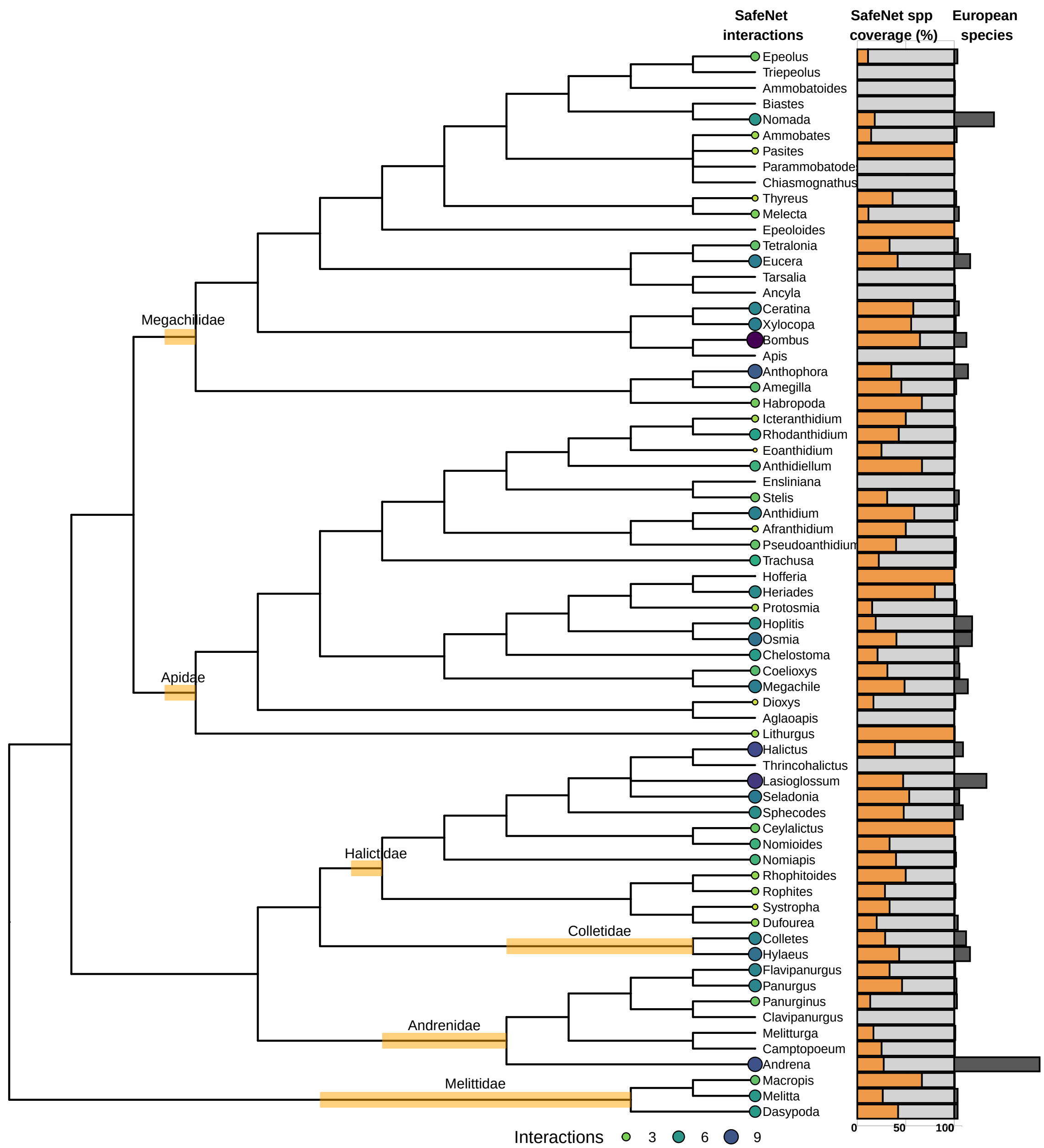

Figure 2. Phylogenetic representation of bee genera in the SafeNet database within the context of all European bee genera. The number of interactions recorded per genus in the database is illustrated using circles, with their sizes proportional to the number of interactions on a logarithmic scale. Additionally, a gradient of colors ranging from yellow to dark purple aids in this visualization. The coverage of species recorded in SafeNet per genus at the European level is depicted with orange and light grey bars, representing the percentage of species included and not included in the database, respectively, out of the total number of bee species per genus at the European level. Grey bars indicate the total number of species per genus at the European level.

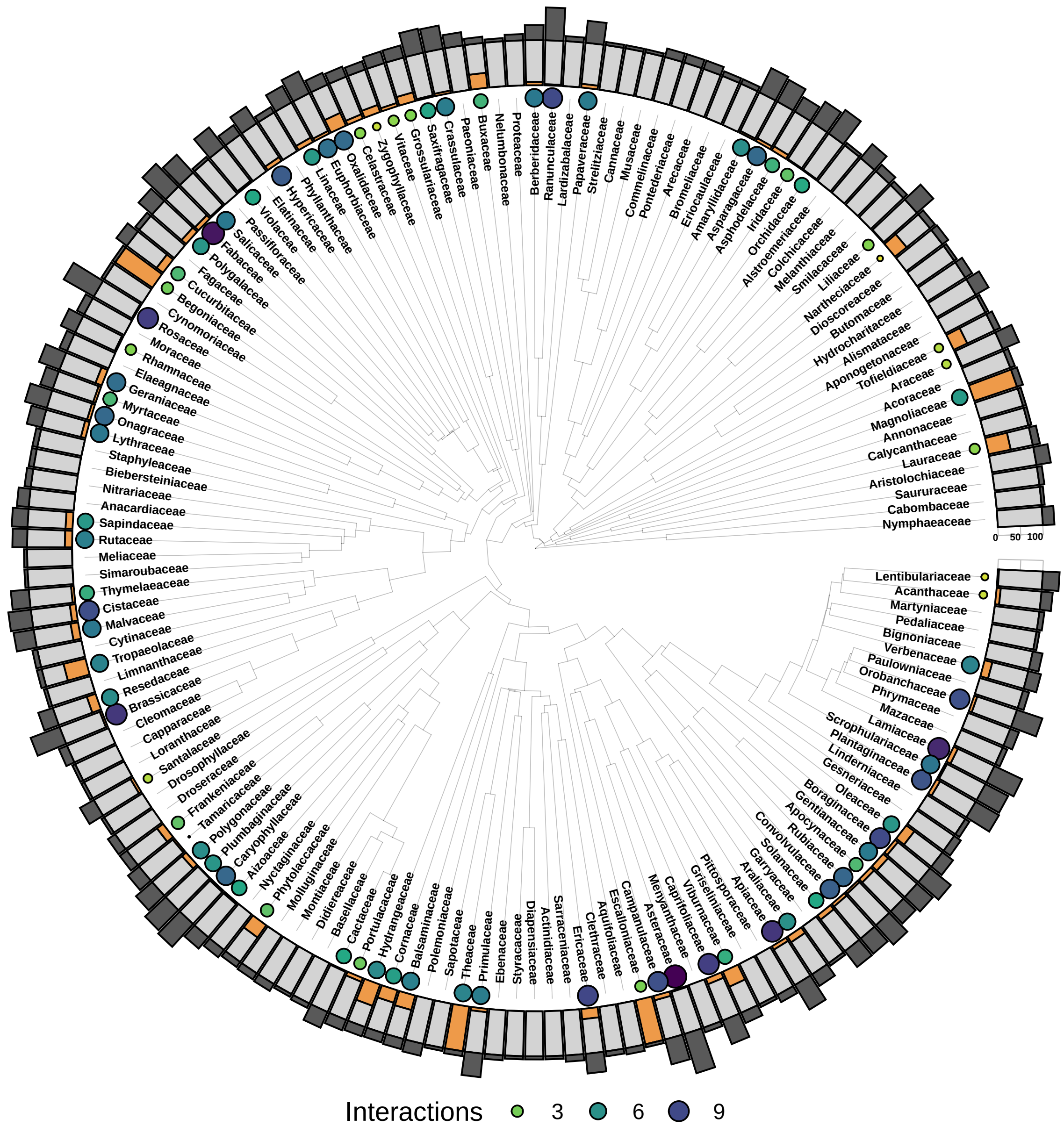

Figure 3. Phylogenetic representation of the plant families in the SafeNet database within the context of all flowering plant families occurring in Europe. The number of interactions recorded per genus in the database is illustrated using circles, with their sizes proportional to the number of interactions on a logarithmic scale. Additionally, a gradient of colors ranging from yellow to dark purple aids in this visualization. The coverage of species recorded in SafeNet per genus at the European level is depicted with orange and light grey bars, representing the percentage of species included and not included in the database, respectively, out of the total number of flowering plant species per family at the European level. Grey bars indicate the total number of species per family at the European level on logarithmic scale.

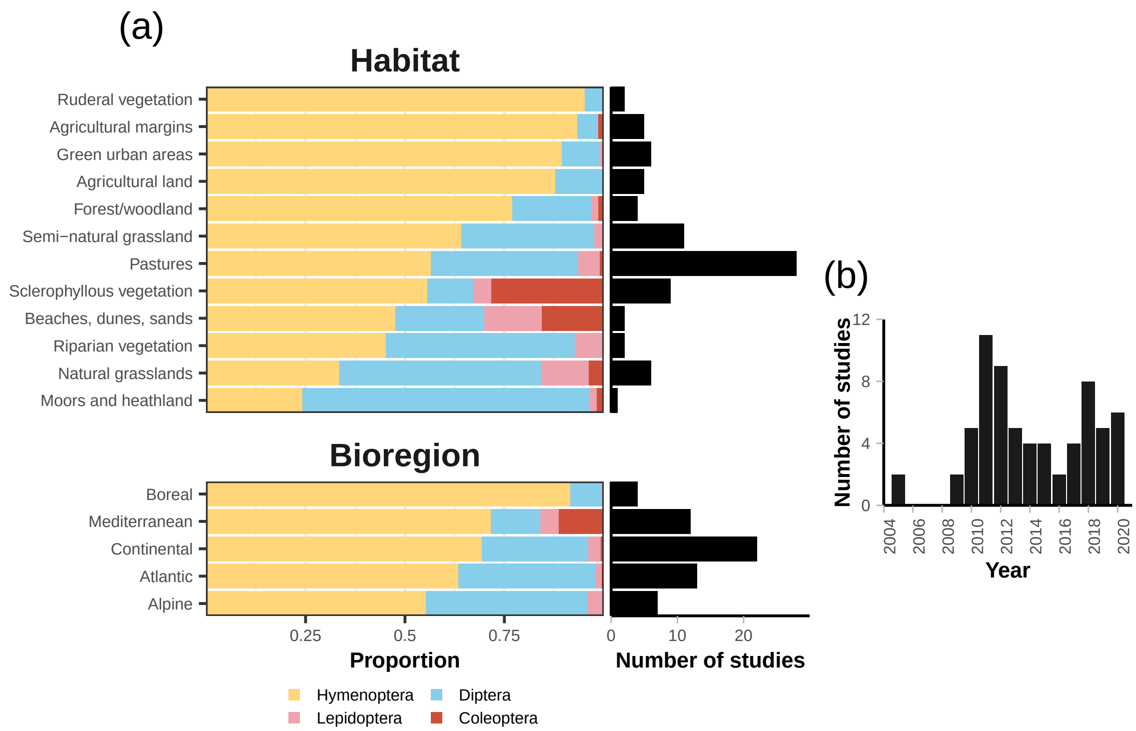

Figure 4. Proportion of the major pollinator orders by habitat types and bioclimatic regions in the SafeNet database. The orders, from left to right, include Hymenoptera, Diptera, Lepidoptera and Coleoptera. The horizontal barplot on the right indicates the number of studies that were conducted on each habitat type or bioclimatic region. Note that a single study can countribute to more than one habitat or bioclimatic region. Areas with a greater number of studies are more likely to depict accurate proportions of pollinators in those systems.

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Author contributions

Supplementary material

Supplementary text 1

Habitat definitions:

1) **Ruderal vegetation**: Plants growing on highly disturbed sites such as road sides or mineral extraction sites.

2) **Agricultural margings**: Sides of crops that can include any type of vegetation from low growing plants to trees.

3) **Green urban areas**: Parks, private gardens or small pastures within an urban setting. Botanical gardens are included in this category.

4) **Agricultural land**: Includes any type of crop and any type of vegetation growing within them.

5) **Forest/woodland understory**: Any plant community sampled under a wooded group of plants. The forest could be embedded in an agricultural setting or in a fully natural scenario. We have included here agro-forestry areas and open to dense forest. Note that we have excluded from this category forest that contains sclerophyllous vegetation.

6) **Semi-natural grassland**: Low growing plant community with relatively low disturbances but under low pressure such as seasonal mowing or extensive grazing.

7) **Pastures**: Any type of low growing plant community that is highly influenced by human disturbance. For instance, agriculture, mowing, moderate to high grazing or urban environments. Note that this category also includes old pastures with regrowth of woody vegetation.

8) **Sclerophyllous vegetation**: Any type of system with a dominant shrub community adapted to drought. Typical of the Mediterranean region. Note, that we have include in this category also woodlands (open coniferous forest) where the shrub community was the main focus of the study.

9) **Beaches, dunes, sands**: Plant communities growing on sandy soil.

10) **Riparian vegetation**: Plant communities growing on river margins.

11) **Natural grassslands**: Low growing plant communities with little or none human disturbance. Often located in high elevation areas within Europe.

12) **Moors and heathland**: Low growing woody vegetation characteristic from low fertile soils near the coast or in alpine areas.