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Insect Conservation and Diversity

National records of 3000 European bee and hoverfly species: A contribution to pollinator conservation

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Abstract

1. Pollinators play a crucial role in ecosystems globally, ensuring the seed production of most flowering plants. They are threatened by global changes and knowledge of their distribution at the national and continental levels is needed to implement efficient conservation actions, but this knowledge is still fragmented and/or difficult to access.
2. As a step forward, we provide an updated list of around 3000 European bee and hoverfly species, reflecting their current distributional status at the national level (in the form of present, absent, regionally extinct, possibly extinct or non-native). This work was attainable by incorporating both published and unpublished data, as well as knowledge from a large set of taxonomists and ecologists in both groups.
3. After providing the first National species lists for bees and hoverflies for many countries, we examine the current distributional patterns of these species and designate the countries with highest levels of species richness. We also show that many species are recorded in a single European country, highlighting the importance of articulating European and national conservation strategies.
4. Finally, we discuss how the data provided here can be combined with future trait and Red List data to implement research that will further advance pollinator conservation.

KEYWORDS
Anthophila, Apoidea, centralised occurrence records, country records, Diptera, expert knowledge, Hymenoptera, pollination, species checklists, Syrphidae

INTRODUCTION

Pollinators play a crucial role in ecosystems globally, ensuring the seed production of most flowering plants (Ollerton et al., 2011). Bees are recognised as the most important pollinator group (Ballantyne et al., 2017; Willmer et al., 2017), followed by hoverflies as another significant group of pollinating insects (Doyle et al., 2020; Lucas et al., 2018). Hoverflies are also effective bioindicators (Burgio & Sommaggio, 2007; Dziock, 2006; Popov et al., 2017), and some species provide biological control (Dunn et al., 2020; Pekas et al., 2020; Rodríguez-Gasol et al., 2020) in agricultural systems as natural predators of crop pests. Bees and hoverflies show a cosmopolitan distribution in all continents except Antarctica. Bees are more diverse in dry and warm areas, with the Mediterranean basin being one of the most important hotspots for species diversity (Michener, 1979; Michez et al., 2019; Orr et al., 2021). Hoverflies are found from arid steppes and semi-deserts, throughout all types of forests, to the polar tundra in the north (Rotheray & Gilbert, 2011). The documented global diversity of bees (Hymenoptera: Apoidea: Anthophila) is above 20,000 species in seven families (Ascher & Pickering, 2020), while the diversity of hoverflies (Diptera: Cyclorrhapha) is around 6300 species in one family (the Syrphidae) (Skevington et al., 2019).

An increasingly large proportion of the world's entomofauna is declining (Goulson, 2019; Hallmann et al., 2017), including pollinators (Dicks et al., 2021; Fromentin et al., 2022; Potts et al., 2010). In particular, negative population trends were demonstrated in some wild bees and hoverflies (Biesmeijer et al., 2006; Potts et al., 2015; Powney et al., 2019). Pollinators have been under the spotlight for some years, and at the European level, work has been centralised under the EU Pollinators Initiative within the EU Biodiversity Strategy for 2030 (European Commission, 2021). One of the most relevant projects dealing with bees and hoverflies was the project STEP—Status and Trends of European Pollinators (2010–2015; Potts et al., 2015). In this framework, the first European Red List of Bees was published (Nieto et al., 2014), one of whose main findings was the demonstration of a severe lack of knowledge for 55% of the more than 1900 assessed species (i.e., they were listed as Data Deficient). After this, numerous European projects were devoted to the subject of bee decline. Interest in and knowledge about hoverflies is also slowly rising, highlighted by an increase in the number of papers on hoverflies (Clarivate Web of Science, 2022), as well as hoverfly conservation actions funded by the EU. As such, during the 2018–2022 period, the first-ever IUCN European Red List of Hoverflies was realised (Vujić, Gilbert, et al., 2022). Building upon this project's outputs, a further study was carried out aimed at defining specific conservation measures for their preservation and mapping potential stakeholders (IUCN SSC HSG/CPSG, 2022).

Overall, one of the most critical messages highlighted by both bee and hoverfly Red Lists is the need to improve knowledge of the spatial distribution of most species. Building on the previous knowledge base, the project 'SPRING—Strengthening Pollinator Recovery through INdicators and monitorinG' aims to set a baseline for a European scale long-term monitoring of pollinators, the EU Pollinator Monitoring Scheme (EU-PoMS, Potts et al., 2020), and start European-wide monitoring of pollinators to detect changes in the status of several pollinator groups using standardised sampling methods.

Among countries, knowledge of the distribution of pollinators is most often largely uneven (Boyd et al., 2022; Potts et al., 2020). Northwest European countries have a long tradition of recording bees and hoverflies, while several eastern and Mediterranean countries do not have historical records and current national checklists (Ghisbain, 2021). In the absence of national and centralised databases of occurrence records, it remains challenging to understand the large-scale patterns of wild bee and hoverfly diversity across gradients of climatic conditions, vegetation, population density, etc. To date, this information has been mostly scattered in multiple taxonomic and faunistic publications, buried in private and public natural history collections or unpublished databases, making access to the currently available knowledge extremely complicated. Efforts to improve, centralise and stimulate the availability of publicly available data should be encouraged to improve the assessment of species distributions and their trends: the EU-PoMS aims to tackle this question to facilitate insect monitoring across spatial scales. All the EU-27 countries will be required to start a long-term pollinator monitoring scheme in the next few years. Furthermore, Member States will possibly be required to report on pollinator trends under the legally binding target of the Nature Restoration Law proposal, which sets the objective of reversing pollinator decline by 2030 and achieve a continuously increasing trend (European Commission, 2022). Fundamental to these activities is the existence of an up-to-date reference list of all the species potentially discoverable in each country during monitoring. Because we cannot protect what we do not know about, the first step for conserving pollinators is documenting which species exist in Europe, and where they occur.

This study builds on a similar project on the European butterflies that resulted in the recent publication of an updated European checklist with country records (Wiemers et al., 2018). Here we dealt with two groups of insects, an effort that has been useful to bring the scientific community together to work towards a shared objective. Joint efforts are especially relevant because the three groups of insects (butterflies, hoverflies and bees) will be monitored together in the EU-PoMS, so close collaboration between scientific communities will be fundamental for the strategy's success. This paper presents the current state of our knowledge of pollinator distributions at the European, country and subnational levels (using a modified version of the IUCN European country list) for both bees and hoverflies, integrating published and unpublished records, as well as expert knowledge.

MATERIALS AND METHODS

Geographical framework and country list

The geographical scope for this study was the territory included within the European assessments for the IUCN. We used the country list of the IUCN, including subnational divisions (mainland territories of European countries and biogeographically separated entities such as archipelagos, peninsulas, parts of islands), with some modifications (listed below). This country list and subnational divisions are based on the World Geographical Scheme for Recording Plant Distributions published for the International Working Group on Taxonomic Databases for Plant Sciences (Brummitt, 2001). The following countries and political entities were considered: Albania, Andorra, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Faroe Islands, Finland (separating Åland Islands from mainland), France (separating Corsica from mainland), Germany, Gibraltar, Greece (separating Crete and the East Aegean Islands from mainland), Hungary, Iceland, Ireland, Isle of Man, Italy (separating Sardinia and Sicily from mainland), Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Moldova, Montenegro, the Netherlands, North Macedonia, Norway, Poland, Portugal (separating the Azores and Madeira archipelagos from mainland), Romania, Russian Federation (the European part), Serbia, Slovakia, Slovenia, Spain (separating the Balearic Islands and the Canary Islands from mainland), Sweden, Switzerland, Turkey (the European part), Ukraine (separating Crimea from the main part) and United Kingdom (separating Great Britain from Northern Ireland). For each country with different entities, we considered each entity separately and generated a category for the country as a whole in order to have the national total. We did not include the following entities for which we did not have a dataset for both bees and hoverflies: Vatican City, San Marino, Monaco, Jersey and Guernsey.

Data sources

For bees, we considered 2138 species from the most recent list of Ghisbain, Rosa et al. (2023), which is based on the first European Red List of Bees (Nieto et al., 2014), updated by Rasmont et al. (2017). Country-occurrence lists of European bees were compiled through revision of available literature comprising national Red Lists, checklists, atlases of European countries, published keys, species-based portals and other taxonomic publications (Supplementary Material 1). Additionally, publicly available, private and institutional databases were used, such as GBIF (GBIF.org, 2022), FinBIF (FinBIF, 2022) and a database deposited at the Laboratory of Zoology, Research Institute for Biosciences, University of Mons (Belgium). Knowledge from expert taxonomists and ecologists was especially critical to evaluate the data retrieved from online databases, as the latter include a substantial proportion of potentially erroneous occurrence records uploaded by non-experts, so the validation of data coming from this type of sources is necessary.

Country-occurrence lists of European hoverflies (encompassing 913 species in total) were compiled based on the data collected for the needs of the European Red List of Hoverflies (Vujić, Gilbert, et al., 2022), which was primarily based on SyrphThe Net (Speight et al., 2015), updated by the most recent publications of species occurrences across Europe. Nomenclatural changes between the IUCN Red List of Hoverflies and the list used in the present work are elaborated in Tot et al. (in prep.). The main literature sources used for the Red List assessments, and updates of the List, were the published Red Lists, checklists, atlases of European countries, published keys, species-based portals and other taxonomic publications (Supplementary Material 1). Additionally, publicly available, private and institutional databases were used, such as GBIF (GBIF.org, 2022), FinBIF (FinBIF, 2022) and a database deposited in the Department of Biology and Ecology, Faculty of Sciences, University of Novi Sad, Serbia.

Compilation of data

All data collected from different sources were aggregated in a table presenting species in rows and countries in columns (Supplementary Material 2). We used the following five categories for each species in every country.

- P = Present. The species is recorded in the country or its subdivision in literature records or collections, is marked as "extant" (=living) in the country based on the IUCN or based on expert opinion.
- A = Absent. There is no record of the species in the country, or the existing published records referring to the particular species were considered dubious by experts.
- RE = Regionally Extinct. The species has been evaluated largely following IUCN criteria and has been found to have disappeared from the national territory of the country. Used only for countries where national Red Lists are available (see *Data* sources).
- PE = Possibly Extinct. This category has followed expert criteria. The expert taxonomist in charge of the group considers that the species is extinct in the precise country, even though there is not a Red List available, or the list is outdated for that country, or the species was not evaluated as extinct in it.
- NN = Non-native. Species whose original distribution range does not encompass Europe, but have been introduced to European territory through human activities.

The categories "possibly extant" and "presence uncertain" used in the Red List of Hoverflies were transformed to "present" or "absent" based on expert opinion. For species recorded as NA in national Red Lists, which are probably casual encounters, any of the considered categories was assigned, according to expert opinion.

Validation of the datasets

Once the two first authors compiled a first draft of the table, it was sent for further checks. For bees, it was sent to people hosting data at the national level, who checked the data from their country and validated the records, removing apparent mistakes and including any missing published data and unpublished data from museums, historical collections, research centres and others. Once this phase was finished, the table was sent to expert taxonomists according to their clade of expertise. These experts conducted additional checks of the dataset and updated the table with new information based on additional published literature and/or unpublished private or institutional databases. For hoverflies, a draft table was sent to a core team of experts, based on their geographical expertise. Afterwards, the core team of experts further engaged additional expert taxonomists for particular cases, based on their geographical or taxonomic expertise. Finally, records were removed that were considered by the experts as clear mistakes, misidentifications or dubious records on published or unpublished sources. The list of all experts for both groups, along with their expertise, is given in Supplementary Material Supplementary Material 3.

After expert checks, the occurrences of six hoverfly and one bee species originally marked as occurring in a single country were transformed to absences, resulting in a species being on the list, but not being marked as present in any of the countries. Such species were kept in the list because their presence was suspected in Europe, but their distribution remains unclear.

The scheme of the entire workflow is shown in Figure 1.

RESULTS

Records of 2138 bee species and 913 hoverfly species in total were recorded within the geographical scope of this study. The number of species per country ranged from 7 to 1187 species for bees and from 24 to 566 species for hoverflies (Figure 2a,b and Table 1). The European country with the highest number of recorded bee species was Greece (1187 species), followed by Spain (1171 species) and Italy (1050 species). Regarding hoverflies, France was the most species-rich (566 species), followed by Italy (513 species), Switzerland (492 species) and Germany (467 species).

Considering the distribution of the species themselves, 552 bee species were recorded from only one European country, 255 species in two countries and 161 species in three countries. The remaining 1170 species were recorded in four or more countries (Figure 3a). Focusing on the species recorded from a single European country, the countries with the highest number of such species were Greece, with 175 species not found anywhere else in Europe (77 only in mainland Greece, 26 in the East Aegean Islands and 19 only in Crete), Spain with 171 species (of which 86 were found only in mainland Spain, 75 only in the Canary Islands and 2 only in the Balearic Islands) and the third being Cyprus with 65 species not found anywhere else in Europe (Figure 4a and Table 1). It is however important to emphasise that a proportion of these species is also present in North Africa or the Middle East, and hence not all of these species are actually endemic to Europe. For hoverflies, 134 species were recorded only from one country, 65 in two countries, 62 in three countries and 643 in four or more countries (Figure 3b). The remaining six species did not have associated country records. The countries with the highest number of hoverfly species recorded only from one country in Europe were Greece, with 44 species (16 found only in mainland Greece, 14 only in the East Aegean Islands and 5 only in Crete), Spain with 29 species (17 only in mainland Spain, 11 only in the Canary Islands and 1 only in the Balearic Islands), and then France and Russia (the European part) with nine species each (Figure 4b and Table 1).

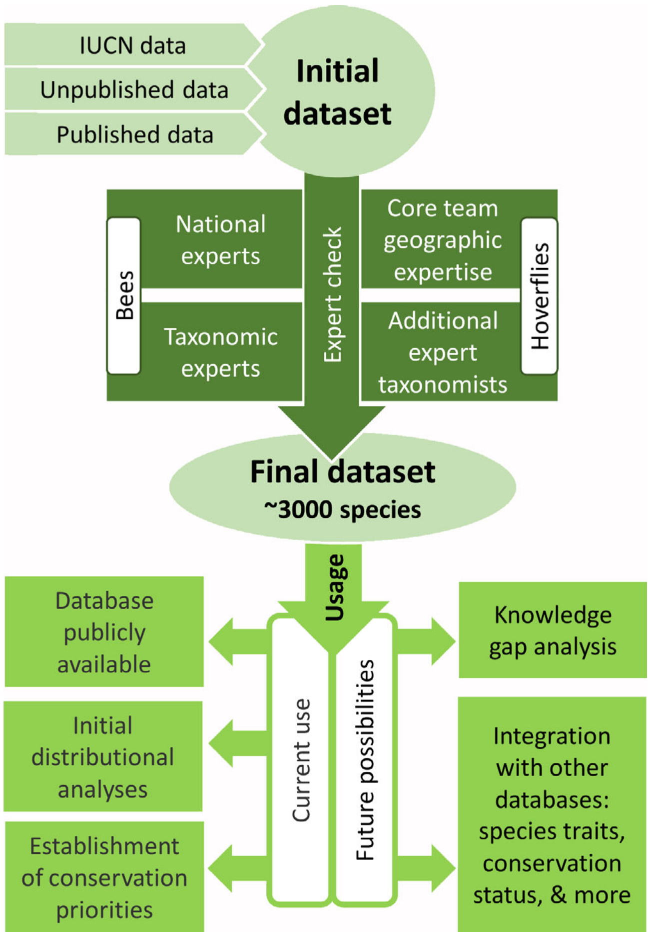


FIGURE 1 Graphical representation of the workflow of the study, with potential usage of the dataset.

For bees, we provide the first species checklists for Albania, Bosnia and Herzegovina, Croatia, Greece (separating Crete and the East Aegean Islands), Moldova, Montenegro, North Macedonia, Ukraine (separating Crimea) and Turkey (the European part). As for hoverflies, the first country and political/geographical entities lists are given for Albania, Bosnia and Herzegovina, Croatia, Cyprus, Moldova and Turkey (the European part).

DISCUSSION

In this paper, we provide data on the country-level occurrences of European bee and hoverfly species. In the initial set of analyses, we focus on exploring the main distributional patterns by presenting species-richness patterns across countries. We explore the number of occurrences of each species across European countries, including the richness of species occurring only in a single European country, because it is particularly relevant to detect diversity hotspots of these species, and to understand the distribution of species with narrow distributions on the continent, so as to be able to set conservation priorities.

Spatial distribution of diversity

For bees, we found the Mediterranean countries to host the highest diversity, as previously observed by other authors (Leclercq et al., 2022; Michener, 2007; Nieto et al., 2014; Orr et al., 2021). The three most species-rich countries for bees are Greece, Spain and Italy. This pattern is explained by the fact that bees show a higher diversity in warm and dry areas (Michener, 2007). Southern Europe acted as an important refugia for many groups during glaciations (Bilgin, 2011; Hewitt, 2004), including bees (Dellicour et al., 2014, 2017; Lecocq et al., 2013). All these three richest countries connect Europe to the Mediterranean parts of Africa and Asia. For that reason, Greece is the most species-rich country in Europe and the country that hosts the most single-country occurring species. Italy is connected to Africa through Sicily, very close to Tunisia, and has 15 species that occurred only there in Europe. On the other side, Spain is a connection between the western European and North African faunas, and for this reason hosts many bees that do not occur anywhere else in Europe (Bartomeus et al., 2022; Radchenko et al., 2019; Wood et al., 2021), some of them being only present in the Canary Islands (Gobierno de Canarias, 2022). The Iberian Peninsula, like Greece, is also hosting

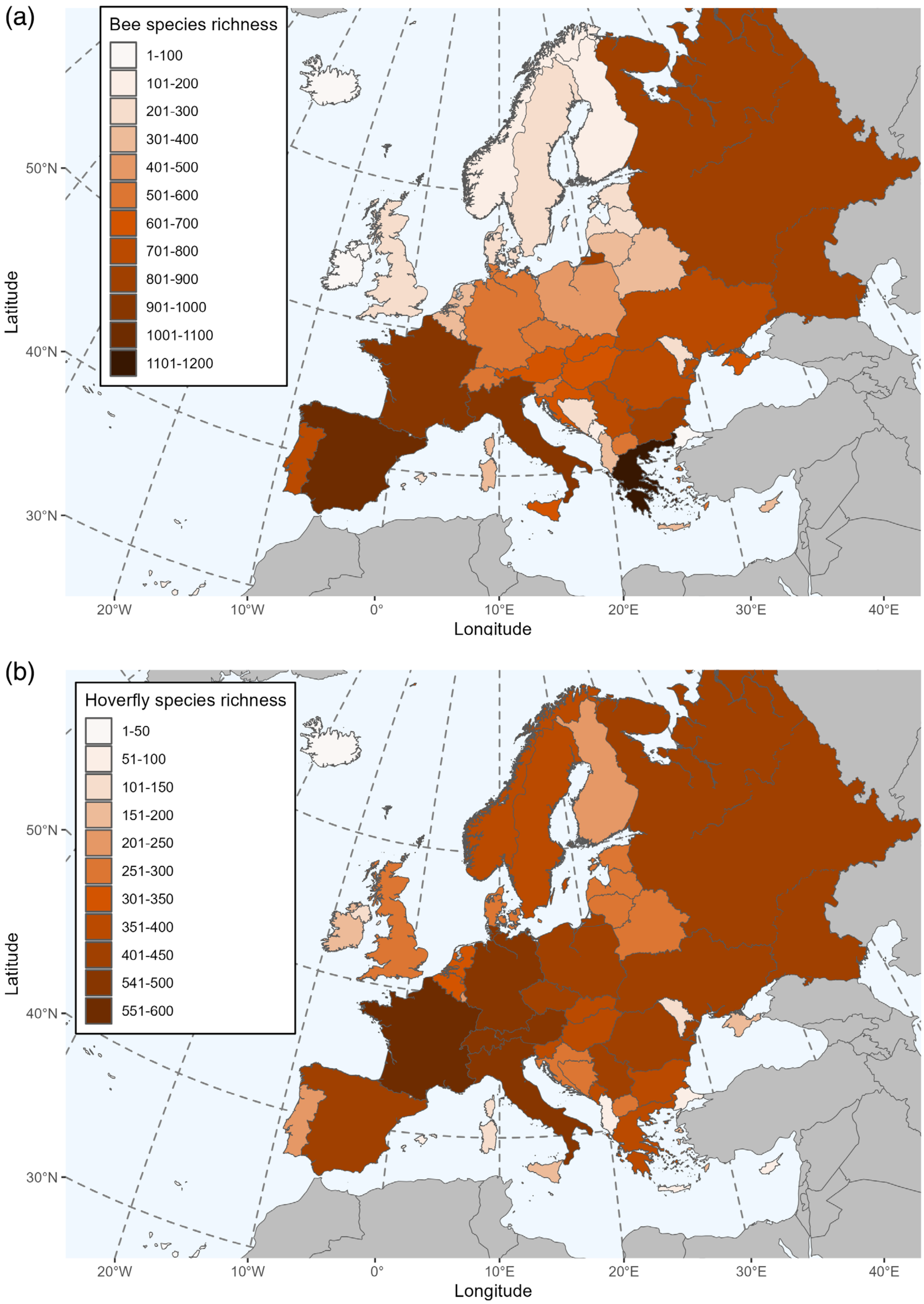


FIGURE 2 Map of Europe, representing the richness of bee (a) and hoverfly (b) species recorded in each country (or sub-country unit) or its European part. Countries in grey colour were not included in this study.

many European endemic species while there are few endemic species in Italy (e.g. Ghisbain, Radchenko, et al., 2021; Michez & Eardley, 2007; Nieto et al., 2014). In contrast, hoverflies show a different pattern. Countries in temperate Europe show similar species-richness trends. It is important to highlight, however, that even if similar in species richness, the composition of hoverfly fauna in the Mediterranean region differs from that of the rest of temperate Europe, a pattern established in previous studies (Grković et al., 2015; Petanidou et al., 2011). Similarly, the hoverfly composition of northern Europe, although poorer, is also quite distinctive, with many species

TABLE 1 Number of species present (P), possibly extinct (PE), regionally extinct (RE), non-native (NN) and species recorded only in that European country or sub-country unit (1 country).

	Bees					Hoverflies				
Country	P	PE	RE	NN	1 country	P	PE	RE	NN	1 country
Albania	335	0	0	0	1	85	0	0	0	0
Andorra	108	0	0	0	0	185	0	0	0	0
Austria	680	33	0	1	1	465	20	0	0	0
Belarus	356	0	0	0	1	252	0	0	0	0
Belgium	390	1	15	0	0	341	12	0	0	0
Bosnia and Herzegovina	292	0	0	1	0	259	1	0	0	0
Bulgaria	830	0	0	0	9	386	1	0	0	1
Croatia	665	0	0	1	1	289	2	0	0	0
Cyprus	385	0	0	0	65	73	0	0	0	6
Czech Republic	549	0	78	0	0	412	2	6	0	0
Denmark	274	0	19	1	0	277	0	10	0	0
Estonia	266	0	14	0	0	270	0	0	0	0
Faroe Islands	7	0	0	0	0	28	0	0	0	0
Finland	224	4	10	2	0	359	0	10	0	3
Finland—Åland Islands	146	4	2	1	0	220	0	0	0	0
Finland—Mainland	219	4	9	2	0	359	0	10	0	3
France	973	0	0	2	6	566	10	0	0	9
France—Corsica	309	0	0	0	4	111	2	0	0	5
France—Mainland	948	0	0	2	1	553	9	0	0	3
Germany	558	0	38	1	0	467	6	5	0	0
Gibraltar	35	0	0	0	0	90	0	0	0	0
Greece	1187	0	0	1	175	423	0	0	0	44
Greece—East Aegean Islands	515	0	0	0	26	167	0	0	0	14
Greece—Crete	341	1	0	0	19	83	0	0	0	5
Greece—Mainland	1105	0	0	1	77	381	0	0	0	16
Hungary	700	28	0	1	2	378	1	0	0	0
Iceland	7	0	0	0	0	31	0	0	0	2
Ireland	100	0	2	0	0	184	1	0	0	0
Isle of Man	63	0	0	0	0	112	0	0	0	0
Italy	1050	0	0	2	33	513	1	0	0	5
Italy—Mainland	954	0	0	2	7	496	1	0	0	2
Italy—Sardegna	332	0	0	0	1	111	0	0	0	0
Italy—Sicily	636	0	0	0	15	157	0	0	0	3
Latvia	290	0	1	0	0	297	0	0	0	0
Liechtenstein	233	0	0	1	0	220	1	0	0	0
Lithuania	340	0	0	0	0	260	0	0	0	0
Luxembourg	347	0	0	0	0	201	0	0	0	0
Malta	106	0	0	0	0	52	0	0	0	0
Moldova	220	0	0	0	0	106	0	0	0	0
Montenegro	200	0	0	0	0	386	0	0	0	3
Netherlands	333	0	40	0	0	326	13	0	0	0
North Macedonia	513	0	0	0	3	264	0	0	0	3
Norway	197	0	12	0	0	353	0	1	0	1
Poland	476	0	16	0	0	407	2	0	0	0

TABLE 1 (Continued)

	Bees					Hoverflies				
Country	P	PE	RE	NN	1 country	P	PE	RE	NN	1 country
Portugal	741	0	0	0	10	221	0	0	0	7
Portugal—Azores	18	0	0	0	1	24	0	0	0	2
Portugal—Madeira	18	0	0	0	8	30	0	0	0	4
Portugal—Mainland	732	0	0	0	1	214	0	0	0	1
Romania	763	0	0	1	0	419	0	0	0	3
Russian Federation—European Russia	818	0	0	0	55	405	0	0	0	9
Serbia	707	0	0	1	2	436	3	0	0	3
Slovakia	679	0	0	0	0	389	3	0	0	0
Slovenia	575	0	9	1	0	358	1	0	0	0
Spain	1171	2	0	2	171	426	0	0	1	29
Spain—Balearic Islands	237	0	0	1	2	86	0	0	0	1
Spain—Canary Islands	128	0	0	6	75	47	0	0	1	11
Spain—Mainland	1090	2	0	1	86	408	0	0	0	17
Sweden	281	0	16	0	1	394	2	6	0	1
Switzerland	573	0	56	0	0	493	0	0	0	1
Turkey—European part	44	0	0	0	0	91	0	0	0	0
Ukraine	847	1	0	1	19	421	0	0	0	1
Ukraine—Krym	617	0	0	1	12	189	0	0	0	1
Ukraine—Main part	772	1	0	1	3	402	0	0	0	0
United Kingdom	260	0	14	1	0	279	1	0	0	0
United Kingdom—Great Britain	260	0	14	1	0	279	1	0	0	0
United Kingdom—Northern Ireland	48	0	0	0	0	145	0	0	0	0

restricted to high mountains or the northern parts of Scandinavia. The particularly high species richness in France, Italy and Switzerland is related to high mountains hosting many endemic alpine species. High species diversity and distinct patterns of endemism for different species groups found in alpine areas have previously been recognised (Nagy et al., 2012; Testolin et al., 2021).

The need for supporting taxonomic expertise across Europe

In this project, we provide information on what is currently known regarding the distribution of bees and hoverflies across the countries of Europe. Knowledge on the taxonomy, ecology and distribution of many taxa encompassed by this study is of course prone to changes in the future. Taxonomic revisions are still an ongoing process for some challenging groups, such as the bee genera *Andrena* Fabricius, 1775 (Praz et al., 2022; Wood, 2021; Wood et al., 2021), *Dasypoda* Latreille, 1802 (Ghisbain et al. 2023; Radchenko, 2016, 2017; Radchenko et al., 2019), *Nomada* Scopoli, 1770 (Smit, 2018), *Osmia* Panzer, 1806 (Müller, 2018, 2022b) and *Hoplitis* Klug, 1807 (Müller, 2014a; Müller & Mauss, 2016); and the hoverfly genera *Merodon* Meigen, 1803 (Vujić, Tot, et al. 2021; Vujić, Likov, et al., 2021; Vujić, Radenković, et al., 2020; Vujić, Radenković, et al., 2021; Vujić, Speight, et al., 2020) and *Eumerus* Meigen, 1822 (Aguado-Aranda et al., 2022; Grković et al., 2019, 2021). In these groups, the number of described species (including cryptic ones) is continuously increasing in part thanks to increased access to a large array of diagnostic methods such as DNA barcoding, semio-chemical analysis and geometric morphometrics.

During the development of this project, the need for more people with taxonomic expertise in regions where the fauna is less known became evident. There are many countries for which the recorded number of both bee and hoverfly species is expected to grow in the next years. For bees, the south-eastern part of Europe, especially the Balkans, is where most of the taxonomic work is needed, because historically it has been understudied. As for hoverflies, the highest research gap is also present in Eastern Europe and some countries in the south-east, such as Albania. The problem is not only in the lack of data but also in the possibility that many data records need to be updated and re-verified to be certain about the status in these areas.

Fundamental taxonomic research remains the basis for all subsequent work, from monitoring to species conservation (Ghisbain, Martinet, et al., 2021; Ghisbain, Rosa et al., 2023). Considering the great diversity of insects (including pollinators), more taxonomic work is needed together with the development of taxonomic tools for the relevant groups, both crucial to the understanding of ecology, biogeography and conservation status (Hochkirch et al., 2021; Nieto et al., 2014). Unfortunately, taxonomic expertise is in the hands of a few people, and in many cases there is only one person dealing with a

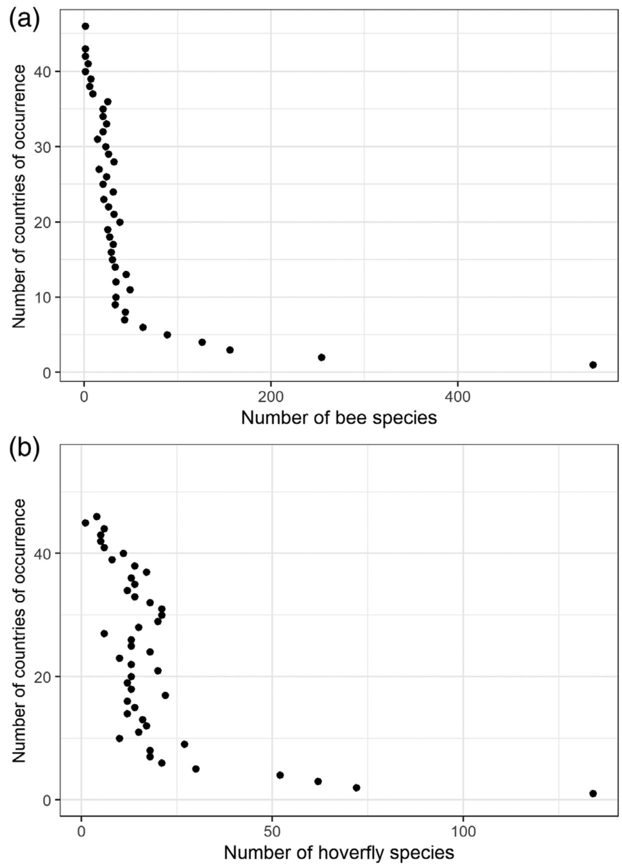


FIGURE 3 Repartition of species of bees (a) and hoverflies (b) within European countries. The *X*-axis represents the number of species and the *Y*-axis represents the number of countries. Only a few species occur in many countries, and many species occur in a small number of countries.

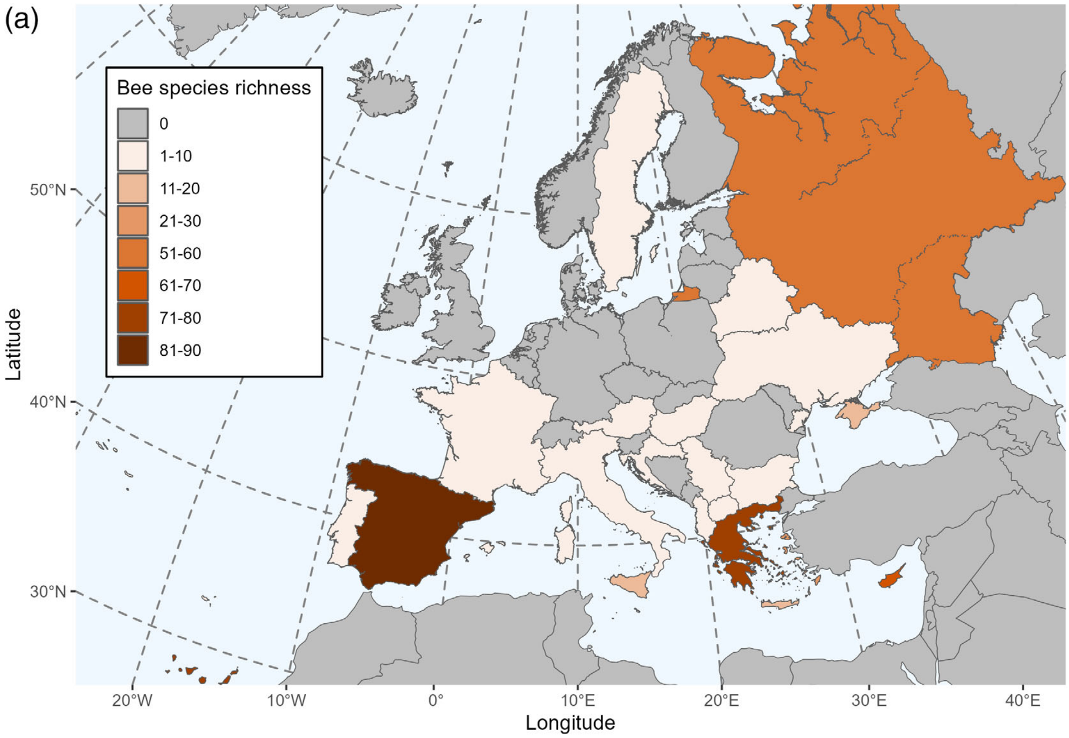
particular genus or species group. Many taxonomists are amateurs because taxonomy is not a well supported professional academic career, despite its importance (Audisio, 2017). It is vital to create such a structure now in order to ensure the continual supply of taxonomic expertise in the future. The European Commission made a start with a project called "The Red List of Insect Taxonomists" (available at https://red-list-taxonomists.eu). This project assessed the available taxonomic expertise on insects across Europe, with particular focus on taxonomists concerned with certain groups, such as pollinators. The main recommendations of the report are support of additional and stable funding for taxonomic research, policy development for taxonomist career, new capacity/networking building for professional and non-professional actors (especially young women) and increasing awareness to general public (Hochkirch et al., 2022).

Towards ambitious programmes of monitoring and conservation

Knowledge about the distribution and population trends of insects is much poorer in comparison to vertebrates with their well-developed monitoring systems allowing continuous evaluation of population size and trends (Brlík et al., 2021; Daskalova et al., 2020; Titley et al., 2017). The situation for insects is more complex due to their extremely high species diversity, mobility and small size, which make observations difficult (especially in flying groups). The expertise and effort needed to identify insects at the species level are often so high that monitoring is badly impeded (Montgomery et al., 2020). Providing basic knowledge in a centralised way on species distributions for all European bee and hoverfly species is already a huge step in building the infrastructure that will enable assessments of their population trends in the future. A lot of information still needs to be compiled to assess the status of species for which distributional data are very limited or unknown. This is especially important in the case of Data Deficient, as well as Endangered and Critically Endangered species in the IUCN Red Lists, for which special efforts must be made to understand their population trends and spatial distribution. Gathering information about species distribution and the assessments of population trends will be the scope of several future projects.

Two major European projects currently aim to centralise and generate taxonomic information for all the species of bees (project ORBIT—Taxonomic resources for European bees) and hoverflies (project Taxo-Fly—Taxonomic resources for European hoverflies) in Europe, both running from 2021 to 2024. These projects aim to develop an online platform hosted by the European Commission containing all the necessary taxonomic information at the species level, which will be updated regularly. These platforms will start functioning within the next two to three years, and hence the data contained in this paper will be essential for supporting monitoring until the updated platforms are available. At the same time, one of the tasks of the project 'SAFEGUARD—Safeguarding European wild pollinators' (2021–2025) is the generation of distribution maps for all European bee, hoverfly and butterfly species. Our information will feed all of these cited projects and several others. During the first months of 2023, the database has been used for the preparation of the update of the European Red List of Bees (project PULSE, 2022–2023). Under the SPRING project, AI applications such as *ObsIdentify* will be used for the automatic recognition of species. Our database will feed these apps, providing country-level information to filter the potential identity of the specimens photographed.

Information provided here will also be helpful for decision-makers at the national scale and even the continental scale when assigning funding for conservation. Knowledge of how species richness and the number of endemics are distributed across space is crucial in determining conservation funding priorities. The focus at the national scale is highly relevant, because national governments are usually the entities in charge of monitoring and conservation (Costa Domingo et al., 2022). We highlight a few countries hosting a large proportion of the number of species of bees and hoverflies recorded in Europe, especially those that do not occur elsewhere across the continent: Greece, Spain, France and Italy. Spain and France already have a National Pollinator Protection Plan set in place (MITECO, 2020; MTE-MAA, 2021). The Greek fauna has been shown to be strongly threatened by global change and human activities, but the protection measures in place are not sufficient, currently covering only a small proportion of the endangered communities (Kougioumoutzis



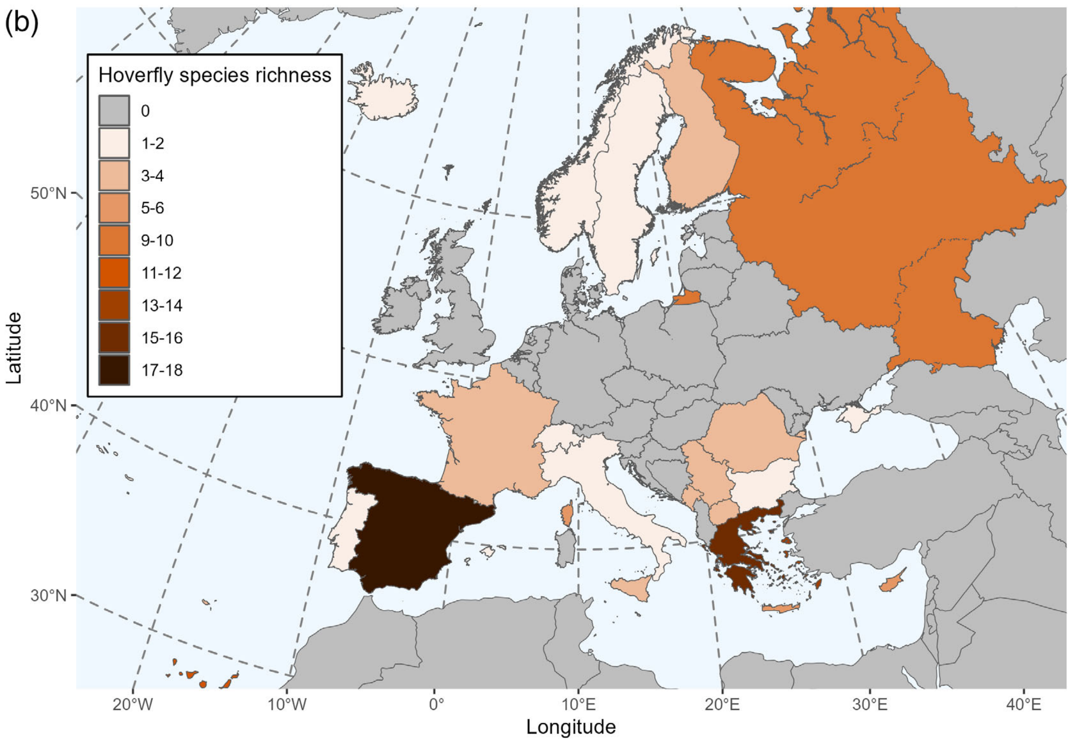


FIGURE 4 Number of bee (a) and hoverfly (b) species recorded only in one European country or sub-country unit.

et al., 2022; Spiliopoulou et al., 2021). Italy faces a similar situation, with a substantial proportion of the pollinators being threatened by extinction (Bonelli et al., 2011; Quaranta et al., 2018). Habitat loss and land-use change constitute a major threat to the diversity of the Mediterranean basin (Falcucci et al., 2007), and so national action plans for pollinator conservation should be a priority there, coordinated with European action plans.

The systematic data we provide here will help countries become aware of their bee and hoverfly richness, especially relevant for many countries where faunistic knowledge is scarce. The data can be used as a starting point for the generation of new national Red Lists or help for national Red Lists that are currently in progress in multiple European countries.

Potential for further exploitation of the dataset

1. Large-scale analyses.

This large-scale database is an excellent reference point in the process of elucidating large-scale patterns on the relationship between the distribution of species and climatic and other abiotic factors. This would allow better understanding of the suitable environmental conditions for each species, providing insights on how and why some species are shifting their distribution ranges across the continent as a consequence of global changes (Ghisbain, Gérard, et al., 2021).

Furthermore, this database provides the possibility of checking the patterns of co-occurrence between species, by testing the patterns of competition or facilitation between species of the same pollinator group, or even between groups at the continental scale.

Nevertheless, the completeness of the information differs strongly between countries (Wetzel et al., 2018). Countries like Moldova, Albania or Montenegro should present a much higher species diversity as expected from the diversity of close countries and their climate. Thus, exploration of the completeness of inventory across countries is an additional topic that should be addressed in subsequent studies, with the results being used to focus on further field investigations. Several previous studies have explored the completeness of inventory of certain areas (Miličić et al., 2020; Russo et al., 2015; Vereecken et al., 2021), sometimes even focusing on particular genera (Jovičić et al., 2017), but a comprehensive study encompassing all species and all European countries would provide important, hitherto unknown information.

2. A collaborative step towards pollinator conservation at the European scale.

In addition to studies about pollinator taxonomy, biogeography and ecology, several ongoing projects are being developed to tackle information gaps about their extinction risks. Availability of distributional, trait and Red List data will provide a fruitful playground for future research that will further advance pollinator preservation. An integrated trait database for European bee and hoverfly species (as an output of the SAFEGUARD project) will provide us a large-scale understanding of how ecological traits can influence the spatial distribution of different pollinator species across the continent. Understanding this relationship will improve our predictive capacity to the potential effects of landscape alteration on community structure, and detect which species are more sensitive to threats and should be prioritised in conservation plans. Another important topic that needs to be addressed in the future is the link between sampling completeness and species traits. Several studies explored whether sampling completeness in plant–pollinator networks was influenced by plant traits (Chacoff et al., 2012; Olito & Fox, 2015), but to the best of our knowledge, testing whether certain traits influence pollinator sampling completeness has not been conducted so far. Moreover, a three-way analysis including species diversity, functional diversity and phylogenetic diversity can provide deep insights into the patterns of speciation and divergence of European species, and shed light on the sensitivity of communities to environmental changes.

Once the update of the European Red List of Bees (project PULSE) is completed, as well as several national Red Lists in which the national scale assessments of bees and/or hoverflies will be delivered, a comparison of the number of threatened European bee, hoverfly and butterfly species across European countries will be very useful as a tool to designate conservation priorities for all major pollinator groups. The information of which countries host the highest concentration of endangered species of different groups will be fundamental for managers and decision-makers to enforce stricter conservation measures.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

ETHICS STATEMENT

No ethical approval was needed for this study, as it does not include any experimental work.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Supplementary Material 1. Part of the literature used to produce country-occurrence lists of European bees and hoverflies.

Supplementary Material 2. Data S1.

Supplementary Material 3. Author Contributions.

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