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► To cite this version:

Sara Reverté, Marija Miličić, Jelena Ačanski, Andrijana Andrić, Andrea Aracil, et al.. National records of 3000 European bee and hoverfly species: A contribution to pollinator conservation. *Insect conservation and diversity*, 2023, 16 (6), pp.758-775. 10.1111/icad.12680 . hal-04337548

HAL Id: hal-04337548

<https://univ-rennes.hal.science/hal-04337548v1>

Submitted on 14 Dec 2023

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

Sara Reverté¹  | Marija Miličić²  | Jelena Ačanski²  | Andrijana Andrić²  |
 Andrea Aracil³  | Matthieu Aubert⁴  | Mario Victor Balzan⁵ |
 Ignasi Bartomeus⁶  | Petr Bogusch⁷  | Jordi Bosch⁸  | Eduardas Budrys⁹  |
 Lisette Cantú-Salazar¹⁰  | Sílvia Castro¹¹  | Maurizio Cornalba¹²  |
 Imre Demeter¹³  | Jelle Devalez^{14,15,16,17}  | Achik Dorchin^{1,18}  |
 Eric Dufrêne¹⁹  | Aleksandra Đorđević²⁰  | Lisa Fisler²¹  | Úna Fitzpatrick²² |
 Simone Flaminio^{1,23}  | Rita Földesi²⁴  | Hugo Gaspar¹¹  | David Genoud²⁵ |
 Benoît Geslin^{26,27}  | Guillaume Ghisbain¹  | Francis Gilbert²⁸  |
 Andrej Gogala²⁹  | Ana Grković²⁰  | Helge Heimburg³⁰  |
 Fernanda Herrera-Mesías^{31,32}  | Maarten Jacobs³³ |
 Marina Janković Milosavljević²⁰  | Kobe Janssen³⁴ | Jens-Kjeld Jensen³⁵ |
 Ana Ješovnik^{36,37}  | Zsolt Józán³⁸ | Giorgos Karlis¹⁵  | Max Kasperek³⁹  |
 Anikó Kovács-Hostyánszki¹³  | Michael Kuhlmann⁴⁰  | Romain Le Divelec¹  |
 Nicolas Leclercq⁴¹ | Laura Likov²⁰  | Jessica Litman⁴²  |
 Toshko Ljubomirov⁴³  | Henning Bang Madsen⁴⁴  | Leon Marshall^{41,45}  |
 Libor Mazánek⁴⁶  | Dubravka Milić²⁰  | Maud Mignot¹  |
 Sonja Mudri-Stojnić²⁰  | Andreas Müller⁴⁷  | Zorica Nedeljković⁴⁸  |
 Petar Nikolić⁴⁹  | Frode Ødegaard⁵⁰  | Sebastien Patiny¹  |
 Juho Paukkunen⁵¹  | Gerard Pennards⁵²  | Celeste Pérez-Bañón³  |
 Adrien Perrard^{53,54}  | Theodora Petanidou¹⁵  | Lars B. Pettersson⁵⁵  |
 Grigory Popov⁵⁶  | Snežana Popov²⁰  | Christophe Praz^{57,58}  |
 Alex Prokhorov⁵⁶  | Marino Quaranta⁵⁹  | Vladimir G. Radchenko⁶⁰  |
 Snežana Radenković²⁰  | Pierre Rasmont¹  | Claus Rasmussen⁶¹  |
 Menno Reemer⁴⁵ | Antonio Ricarte⁴⁸  | Stephan Risch⁶²  |
 Stuart P. M. Roberts⁴¹  | Santos Rojo³  | Lise Ropars⁶³  | Paolo Rosa¹  |
 Carlos Ruiz⁶⁴  | Ahlam Sentil¹  | Viktor Shparyk⁶⁵  | Jan Smit⁶⁶  |

Sara Reverté and Marija Miličić Co-first authors.

Denis Michez and Ante Vujčić Co-last authors.

For affiliations refer to page 769

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Daniele Sommaggio⁶⁷  | Villu Soon¹⁷  | Axel Ssymank⁶⁸  | Gunilla Ståhls⁵²  |
 Menelaos Stavrinides⁶⁹ | Jakub Straka⁷⁰  | Peeter Tarlap¹⁷ | Michael Terzo¹ |
 Bogdan Tomozii⁷¹  | Tamara Tot²⁰  | Leendert-Jan van der Ent⁷²  |
 Jeroen van Steenis⁷³  | Wouter van Steenis⁷⁴  | Androulla I. Varnava⁶⁹  |
 Nicolas J. Vereecken⁴¹  | Sanja Veselić²⁰  | Adi Vesnić⁷⁵  |
 Alexander Weigand³¹  | Bogdan Wisniowski⁷⁶  | Thomas J. Wood¹  |
 Dominique Zimmermann⁷⁷  | Denis Michez¹  | Ante Vujčić²⁰ 

Correspondence

Marija Miličić, BioSense Institute—Research Institute for Information Technologies in Biosystems, University of Novi Sad, Dr Zorana Đinđića 1, 21000 Novi Sad, Serbia.
 Email: marija.milicic@biosense.rs

Funding information

European Commission; Horizon 2020 Framework Programme; SPRING, Grant/Award Number: 09.02001/2021/847887/SER/ENV.D.2; Ministry of Education, Science and Technological Development, Republic of Serbia, Grant/Award Numbers: 451-03-47/2023-01/200125, 451-03-47/2023-01/200358; Science Fund of the Republic of Serbia, Grant/Award Number: 7737504; H2020 Project ANTARES, Grant/Award Number: 739570; ORBIT, Grant/Award Number: 09.029901/2021/848268/SER/ENV.D.2; Taxo-Fly, Grant/Award Number: 09.029901/2021/850402/SER/ENV.D.2; PULSE, Grant/Award Number: 07.027755/2020/840209/SER/ENV.D.2; Status assessment of European Hoverflies (Syrphidae)—European Red List of Hoverflies (EU and pan-Europe), Grant/Award Number: ENV.D.2/SER/2018/0027; SAFEGUARD, Grant/Award Number: 101003476; EU and Greek National Funds, Grant/Award Number: MIS 376737

Editor: Raphael K. Didham and Associate Editor: Michael Garratt

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

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

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: Cyclorhapha) 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 (Niето 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/CPSPG, 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). North-west 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 sub-national 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).

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

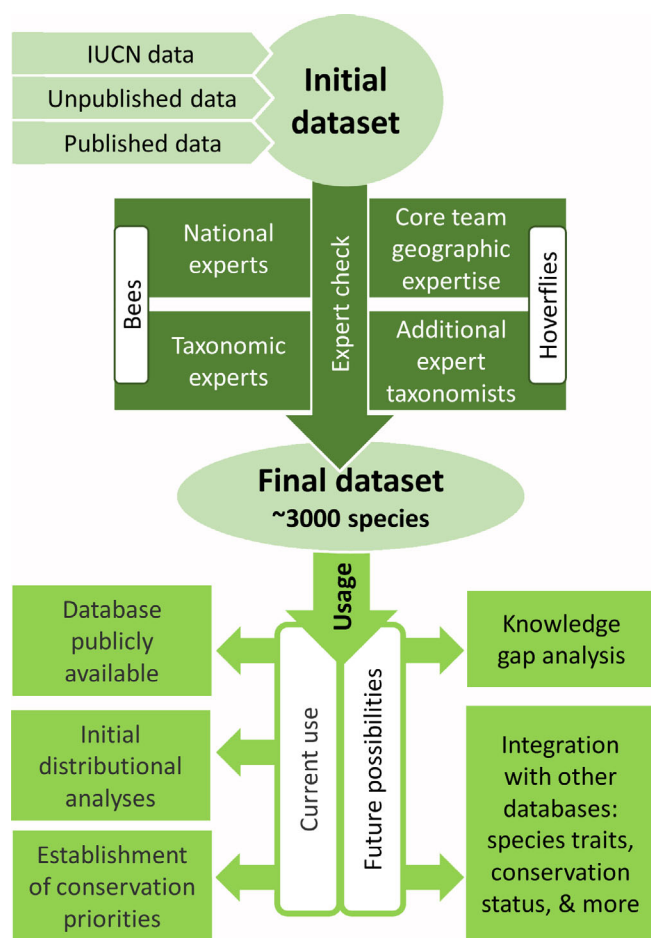


FIGURE 1 Graphical representation of the workflow of the study, with potential usage of the dataset.

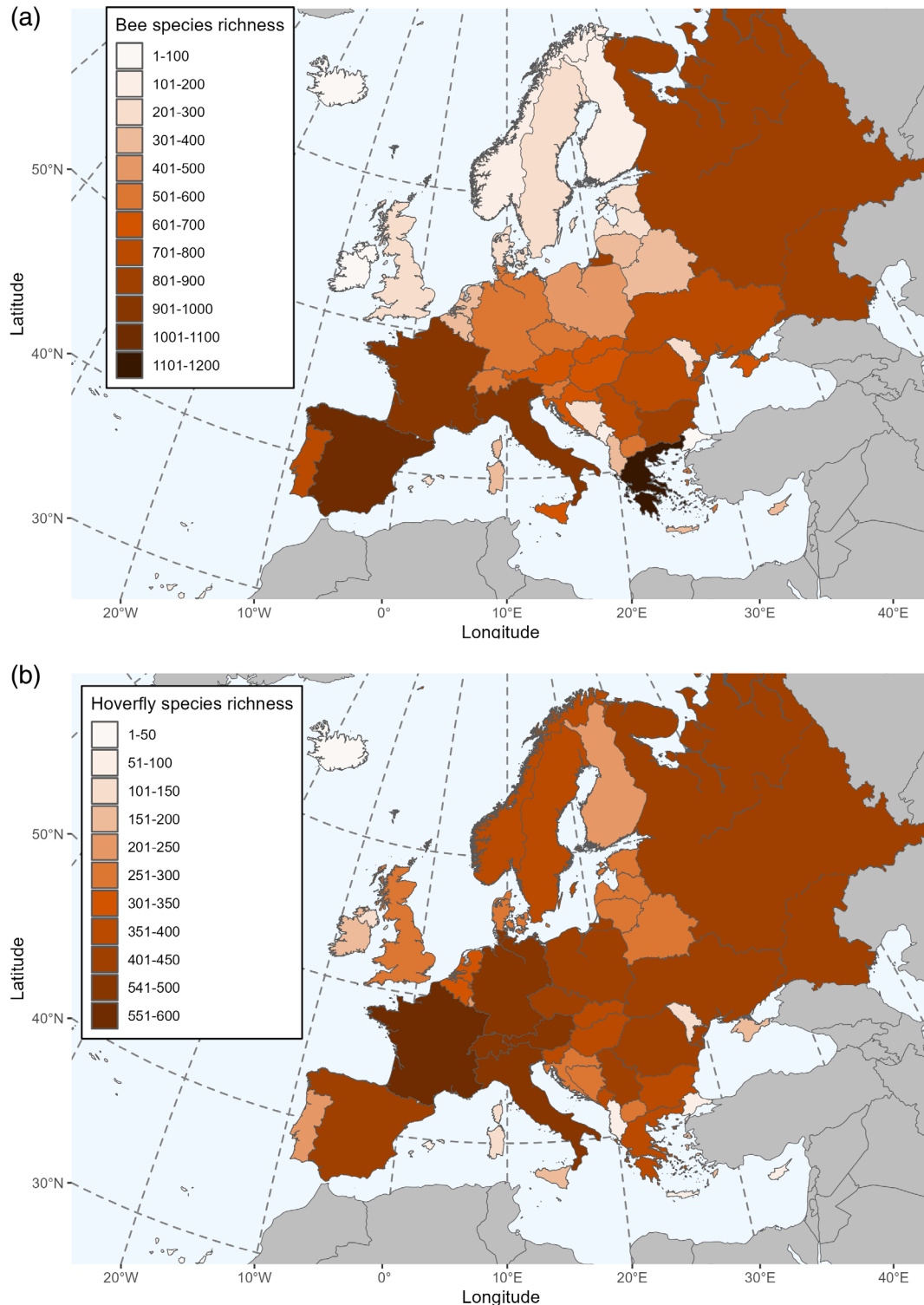


FIGURE 2 Map of Europe, representing the richness of bee (a) and hoverfly (b) species recorded in each country (or sub-country unit) or its European part. Countries in grey colour were not included in this study.

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).

Country	Bees					Hoverflies				
	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)

Country	Bees					Hoverflies				
	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 *Mero-don* 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

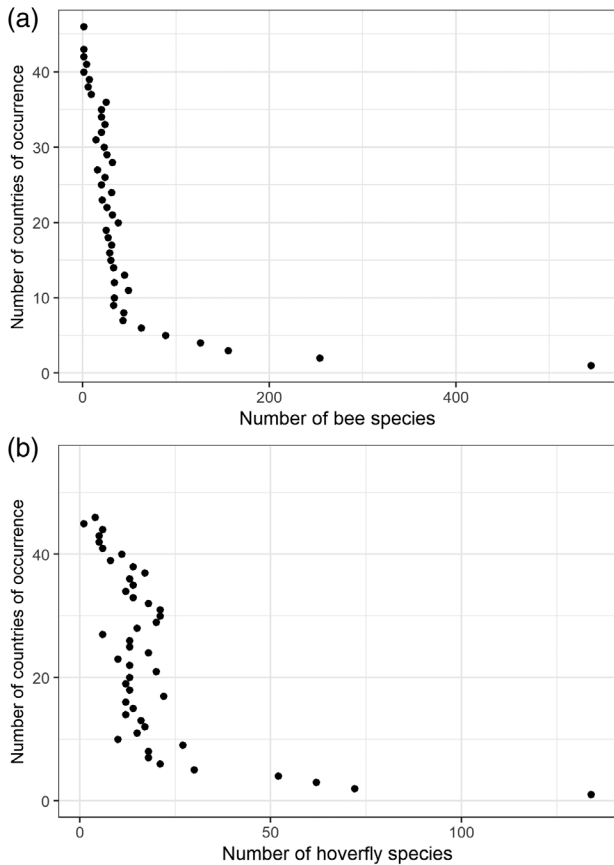


FIGURE 3 Repartition of species of bees (a) and hoverflies (b) within European countries. The X-axis represents the number of species and the Y-axis represents the number of countries. Only a few species occur in many countries, and many species occur in a small number of countries.

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

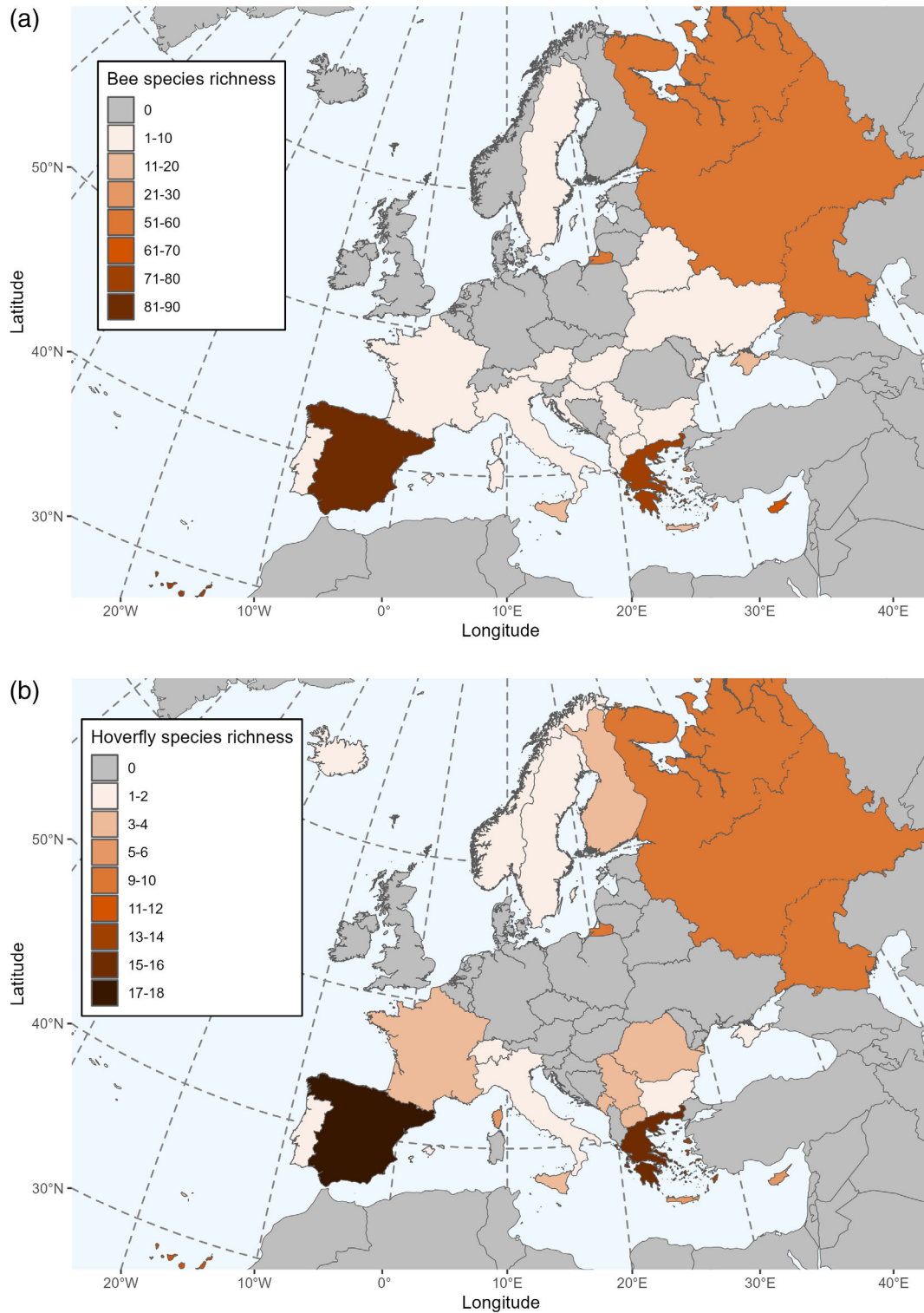


FIGURE 4 Number of bee (a) and hoverfly (b) species recorded only in one European country or sub-country unit.

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.

AUTHOR CONTRIBUTIONS

Marija Miličić: Conceptualization; writing – original draft; formal analysis; data curation; project administration; validation. **Sara Reverté:** Conceptualization; writing – original draft; visualization; validation; formal analysis; data curation; project administration. **Jelena Ačanski:** Validation; writing – review and editing. **Andrijana Andrić:** Validation; writing – review and editing. **Andrea Aracil:** Validation; writing – review and editing. **Mathieu Aubert:** Validation; writing – review and editing. **Mario Balzan:** Validation; writing – review and editing. **Ignasi Bartomeus:** Validation; writing – review and editing. **Petr Bogusch:** Validation; writing – review and editing. **Jordi Bosch:** Validation; writing – review and editing. **Eduardas Budrys:** Validation; writing – review and editing. **Lisette Cantú-Salazar:** Validation; writing – review and editing. **Silvia Castro:** Validation; writing – review and editing. **Maurizio Cornalba:** Validation; writing – review and editing. **Imre Demeter:** Validation; writing – review and editing. **Jelle Devalez:** Validation; writing – review and editing. **Achik Dorchin:** Validation; writing – review and editing. **Eric Dufrière:** Validation; writing – review and editing. **Aleksandra Đorđević:** Validation; writing – review and editing. **Lisa Fisler:** Validation; writing – review and editing. **Úna Fitzpatrick:** Validation; writing – review and editing. **Simone Flaminio:** Validation; writing – review and editing. **Rita Foldesi:** Validation; writing – review and editing. **Hugo Gaspar:** Validation; writing – review and editing. **David Genoud:** Validation; writing – review and editing. **Benoît Geslin:** Validation; writing – review and editing. **Guillaume Ghisbain:** Validation; writing – review and editing. **Francis Gilbert:** Validation; writing – review and editing. **Andrej Gogala:** Validation; writing – review and editing. **Ana Grković:** Validation; writing – review and editing. **Helge Heimbürg:** Validation; writing – review and editing. **Fernanda Herrera-Mesías:** Validation; writing – review and editing. **Maarten Jacobs:** Validation; writing – review and editing. **Marina Janković Milosavljević:** Validation; writing – review and editing. **Kobe Janssen:** Validation; writing – review and editing. **Jens-Kjeld Jensen:** Validation; writing – review and editing. **Ana Ješovnik:** Validation; writing – review and editing. **Zsolt Józán:**

Validation; writing – review and editing. **Giorgios Karlis**: Validation; writing – review and editing. **Max Kasperek**: Validation; writing – review and editing. **Anikó Kovács-Hostyánszki**: Validation; writing – review and editing. **Michael Kuhlmann**: Validation; writing – review and editing. **Romain Le Divelec**: Validation; writing – review and editing. **Nicolas Ledercq**: Validation; writing – review and editing. **Laura Likov**: Validation; writing – review and editing. **Jessica Litman**: Validation; writing – review and editing. **Toshko Ljubomirov**: Validation; writing – review and editing. **Henning Bang Madsen**: Validation; writing – review and editing. **Leon Marshall**: Validation; writing – review and editing. **Libor Mazánek**: Validation; writing – review and editing. **Dubravka Milić**: Validation; writing – review and editing. **Maud Mignot**: Validation; writing – review and editing. **Sonja Mudri-Stojnić**: Validation; writing – review and editing. **Andreas Müller**: Validation; writing – review and editing. **Zorica Nedeljković**: Validation; writing – review and editing. **Petar Nikolić**: Validation; writing – review and editing. **Frode Ødegaard**: Validation; writing – review and editing. **Sebastien Patiny**: Validation; writing – review and editing. **Juho Paukkunen**: Validation; writing – review and editing. **Gerard Pennards**: Validation; writing – review and editing. **Celeste Pérez-Bañón**: Validation; writing – review and editing. **Adrien Perrard**: Validation; writing – review and editing. **Theodora Petanidou**: Validation; writing – review and editing. **Lars B. Petterson**: Validation; writing – review and editing. **Grigory Popov**: Validation; writing – review and editing. **Snežana Jovičić**: Validation; writing – review and editing. **christophe praz**: Validation; writing – review and editing. **Alex Prokhorov**: Validation; writing – review and editing. **Marino Quaranta**: Validation; writing – review and editing. **Vladimir G. Radchenko**: Validation; writing – review and editing. **Snežana Radenković**: Validation; writing – review and editing. **Pierre Rasmont**: Validation; writing – review and editing. **Claus Rasmussen**: Validation; writing – review and editing. **Menno Reemer**: Validation; writing – review and editing. **Antonio Ricarte**: Validation; writing – review and editing. **Stephan Risch**: Validation; writing – review and editing. **Stuart Roberts**: Validation; writing – review and editing. **Santos Rojo**: Validation; writing – review and editing. **Lise Ropars**: Validation; writing – review and editing. **Paolo Rosa**: Validation; writing – review and editing. **Carlos Ruiz**: Validation; writing – review and editing. **Ahlam Sentil**: Validation; writing – review and editing. **Viktor Shparyk**: Validation; writing – review and editing. **Jan Smit**: Validation; writing – review and editing. **Daniele Sommaggio**: Validation; writing – review and editing. **Villu Soon**: Validation; writing – review and editing. **Axel Ssymank**: Validation; writing – review and editing. **Gunilla Ståhls**: Validation; writing – review and editing. **Menelaos Stavrínides**: Validation; writing – review and editing. **Jakub Straka**: Validation; writing – review and editing. **Peeter Tarlap**: Validation; writing – review and editing. **Michael Terzo**: Validation; writing – review and editing. **Bogdan Tomozii**: Validation; writing – review and editing. **Tamara Tot**: Validation; writing – review and editing. **Leendert-Jan van der Ent**: Validation; writing – review and editing. **Jeroen van Steenis**: Validation; writing – review and editing. **Wouter van Steenis**: Validation; writing – review and editing. **Androulla I. Varnava**: Validation; writing – review and editing. **Nicolas J Vereecken**: Validation; writing – review and editing. **Sanja Veselić**: Validation; writing – review and editing. **Adi Vesnić**: Validation;

writing – review and editing. **Alexander Weigand**: Validation; writing – review and editing. **Bogdan Wiśniowski**: Validation; writing – review and editing. **Thomas James Wood**: Validation; writing – review and editing. **Dominique Zimmermann**: Validation; writing – review and editing. **Denis Michez**: Validation; conceptualization; funding acquisition; writing – review and editing; supervision. **Ante Vujić**: Conceptualization; validation; writing – review and editing; supervision; funding acquisition.

AFFILIATIONS

¹Laboratory of Zoology, Research Institute for Biosciences, University of Mons, Mons, Belgium

²University of Novi Sad, BioSense Institute—Research Institute for Information Technologies in Biosystems, Novi Sad, Serbia

³Department of Environmental Sciences & Natural Resources, University of Alicante, Alicante, Spain

⁴Observatoire des Abeilles, Le Méjanel, France

⁵Institute of Applied Sciences, Malta College of Arts, Science and Technology, Paola, Malta

⁶Estación Biológica de Doñana (EBD-CSIC), Sevilla, Spain

⁷Department of Biology, Faculty of Science, University of Hradec Kralove, Hradec Kralove, Czech Republic

⁸CREAF, Autonomous University of Barcelona, Barcelona, Spain

⁹Institute of Ecology, Nature Research Centre, Vilnius, Lithuania

¹⁰Luxembourg Institute of Science and Technology, Esch-sur-Alzette, Luxembourg

¹¹Centre for Functional Ecology—Science for People & the Planet, Department of Life Sciences, University of Coimbra, Coimbra, Portugal

¹²Department of Mathematics, University of Pavia, Pavia, Italy

¹³Centre for Ecological Research, Institute of Ecology and Botany, Lendület Ecosystem Services Research Group, Vácrátót, Hungary

¹⁴Independent researcher, Tartu, Estonia

¹⁵Laboratory of Biogeography and Ecology, Department of Geography, University of the Aegean, Mytilene, Greece

¹⁶Institute of Ecology and Earth Sciences, University of Tartu, Tartu, Estonia

¹⁷University of Tartu Natural History Museum, Tartu, Estonia

¹⁸Musée Royal de l'Afrique Centrale, Tervuren, Belgium

¹⁹12 rue Roger Broussoux, Saint-Hippolyte-du-Fort, France

²⁰Faculty of Sciences, Department of Biology and Ecology, University of Novi Sad, Novi Sad, Serbia

²¹Info fauna—CSCF, Neuchâtel, Switzerland

²²National Biodiversity Data Centre, Waterford, Ireland

²³Centro di Ricerca Agricoltura e Ambiente, (CREA) Consiglio per la Ricerca in Agricoltura e l'analisi dell'Economia Agraria, Bologna, Italy

²⁴Lessingstr. 8, Königsbrunn, Germany

²⁵Avenue des Roses 2, Ambazac, France

²⁶IMBE, Aix Marseille University, Avignon Univ., CNRS, IRD, Marseille, France

²⁷Université de Rennes (UNIR), UMR 6553 ECOBIO, CNRS, Rennes, France

²⁸School of Life Sciences, University of Nottingham, Nottingham, UK

²⁹Prirodoslovni muzej Slovenije, Ljubljana, Slovenia

- ³⁰Landesmuseum Kärnten, Sammlungs- und Wissenschaftszentrum, Klagenfurt am Wörthersee, Austria
- ³¹National Museum of Natural History Luxembourg, Luxembourg City, Luxembourg
- ³²Department of Animal Ecology, Evolution and Biodiversity, Ruhr-Universität Bochum, Bochum, Germany
- ³³Nature-ID, Herentals, Belgium
- ³⁴Dennenweg 118, Zonhoven, Belgium
- ³⁵Í Geilini, Nólsoy, Faroe Islands
- ³⁶Institute for Environment and Nature, Ministry of Economy and Sustainable Development, Zagreb, Croatia
- ³⁷Department of Entomology, National Museum of Natural History, Smithsonian Institution, Washington, DC, USA
- ³⁸Rákóczi u. 5, Mernye, Hungary
- ³⁹Mönchhofstr. 16, Heidelberg, Germany
- ⁴⁰Zoological Museum, University of Kiel, Kiel, Germany
- ⁴¹Agroecology Lab, Brussels Bioengineering School CP 264/02, Université libre de Bruxelles (ULB), Brussels, Belgium
- ⁴²Natural History Museum of Neuchâtel, Neuchâtel, Switzerland
- ⁴³Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria
- ⁴⁴Department of Biology, University of Copenhagen, Copenhagen, Denmark
- ⁴⁵Naturalis Biodiversity Center, Leiden, The Netherlands
- ⁴⁶Jívová 231, Jívová, Czech Republic
- ⁴⁷Institute of Agricultural Sciences, Biocommunication and Entomology, ETH Zürich, Zürich, Switzerland
- ⁴⁸Research Institute CIBIO (Centro Iberoamericano de la Biodiversidad), Science Park, University of Alicante, Alicante, Spain
- ⁴⁹Faculty of Agriculture, University of Banja Luka, Banja Luka, Republic of Srpska, Bosnia & Herzegovina
- ⁵⁰Department of Natural History, Norwegian University of Science and Technology (NTNU), Trondheim, Norway
- ⁵¹Finnish Museum of Natural History LUOMUS, University of Helsinki, Helsinki, Finland
- ⁵²Zangvogelweg 124, Amersfoort, The Netherlands
- ⁵³IEES Paris—Sorbonne Université, CNRS, INRAE, IRD, UPEC, Paris, France
- ⁵⁴Université Paris Cité, Paris, France
- ⁵⁵Department of Biology, Biodiversity Unit, Lund University, Lund, Sweden
- ⁵⁶Department of Entomology and Collection Management, Schmalhausen Institute of Zoology, National Academy of Sciences of Ukraine, Kyiv, Ukraine
- ⁵⁷Info fauna Swiss Zoological Records Center, Neuchatel, Switzerland
- ⁵⁸Institute of Biology, University of Neuchatel, Neuchatel, Switzerland
- ⁵⁹CREA, Council for Agricultural Research and Economics, Roma, Italy
- ⁶⁰Institute for Evolutionary Ecology of the National Academy of Sciences of Ukraine, Kiev, Ukraine
- ⁶¹Department of Agroecology—Entomology and Plant Pathology, Slagelse, Denmark
- ⁶²Imbacher Weg 59, Leverkusen, Germany

- ⁶³Département ThéMA, Université de Franche-Comté, Besançon, France
- ⁶⁴Department of Animal Biology, Edaphology and Geology, Faculty of Sciences, University of La Laguna, La Laguna, Spain
- ⁶⁵Faculty of Natural Sciences, Department of Biology and Ecology, Vasyl Stefanyk Precarpathian National University, Ivano-Frankivsk, Ukraine
- ⁶⁶Voermanstraat 14, Duiven, The Netherlands
- ⁶⁷National Biodiversity Future Center, Department of Life Sciences, University of Modena and Reggio Emilia, Modena, Italy
- ⁶⁸Falkenweg 6, Wachtberg, Germany
- ⁶⁹Department of Agricultural Sciences, Biotechnology and Food Science, Cyprus University of Technology, Limassol, Cyprus
- ⁷⁰Department of Zoology, Faculty of Science, Charles University, Praha 2, Czech Republic
- ⁷¹“Ion Borcea” Natural Sciences Museum Complex, Bacau, Romania
- ⁷²Sara Mansveltweg 19, Wolfheze, The Netherlands
- ⁷³Syrphidae Foundation, Amersfoort, The Netherlands
- ⁷⁴Vrouwenmantel 18, Breukelen, The Netherlands
- ⁷⁵Faculty of Science, University of Sarajevo, Sarajevo, Bosnia & Herzegovina
- ⁷⁶Institute of Agricultural Sciences, Land Management and Environmental Protection, University of Rzeszów, Rzeszów, Poland
- ⁷⁷2nd Zoological Department, Natural History Museum Vienna, Vienna, Austria

ACKNOWLEDGEMENTS

This work was supported by the project SPRING—Strengthening Pollinator Recovery through Indicators and monitoring, EC DG ENV project Contract No: 09.02001/2021/847887/SER/ENV.D.2; Ministry of Education, Science and Technological Development, Republic of Serbia, Grant Nos. 451-03-68/2022-14/200125 and 451-03-68/2022-14/200358, the Science Fund of the Republic of Serbia, project Serbian Pollinator Advice Strategy—for the next normal—SPAS, Grant No. 7737504 and H2020 Project ANTARES, grant no 739570. We also want to thank the Research Institute for Biosciences, University of Mons (Belgium), for support. Other projects that supported the development of this work were: ORBIT—Taxonomic resources for European bees, EC DG Env project Contract No 09.029901/2021/848268/SER/ENV.D.2; Taxo-Fly—Taxonomic resources for European hoverflies, EC DG Env project Contract No: 09.029901/2021/850402/SER/ENV.D.2; PULSE—Providing technical and scientific support in measuring the pulse of European biodiversity using the Red List Index, EC DG ENV project Contract No 07.027755/2020/840209/SER/ENV.D.2; Status assessment of European Hoverflies (Syrphidae)—European Red List of Hoverflies (EU and pan-Europe), project Contract No: ENV.D.2/SER/2018/0027; SAFEGUARD—Safeguarding European wild pollinators, H2020 grant agreement No. 101003476; the project POL-AEGIS (Pollinators of the Aegean: Biodiversity and Threats) co-financed by the EU and Greek National Funds—Research Funding Program: THALES, Grant number MIS 376737.

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.

ORCID

Sara Reverté  <https://orcid.org/0000-0002-2924-3394>
 Marija Miličić  <https://orcid.org/0000-0002-3154-660X>
 Jelena Ačanski  <https://orcid.org/0000-0003-1745-6410>
 Andrijana Andrić  <https://orcid.org/0000-0002-8239-7595>
 Andrea Aracil  <https://orcid.org/0000-0001-5023-6722>
 Matthieu Aubert  <https://orcid.org/0000-0003-2713-9371>
 Ignasi Bartomeus  <https://orcid.org/0000-0001-7893-4389>
 Petr Bogusch  <https://orcid.org/0000-0002-4554-6141>
 Jordi Bosch  <https://orcid.org/0000-0002-8088-9457>
 Eduardas Budrys  <https://orcid.org/0000-0002-2632-0040>
 Lisette Cantú-Salazar  <https://orcid.org/0000-0002-2818-9322>
 Silvia Castro  <https://orcid.org/0000-0002-7358-6685>
 Maurizio Cornalba  <https://orcid.org/0000-0001-7038-6664>
 Imre Demeter  <https://orcid.org/0000-0002-5851-6179>
 Jelle Devalez  <https://orcid.org/0000-0003-1110-0640>
 Achik Dorchin  <https://orcid.org/0000-0003-1151-5926>
 Eric Dufrière  <https://orcid.org/0000-0001-8897-5512>
 Aleksandra Đorđević  <https://orcid.org/0000-0002-8858-9993>
 Lisa Fisler  <https://orcid.org/0000-0002-6291-4540>
 Simone Flaminio  <https://orcid.org/0000-0002-5823-1202>
 Rita Földesi  <https://orcid.org/0000-0002-3500-981X>
 Hugo Gaspar  <https://orcid.org/0000-0001-5448-8396>
 Benoît Geslin  <https://orcid.org/0000-0002-2464-7998>
 Guillaume Ghisbain  <https://orcid.org/0000-0003-2032-8081>
 Francis Gilbert  <https://orcid.org/0000-0002-2727-4103>
 Andrej Gogala  <https://orcid.org/0000-0002-9476-3193>
 Ana Grković  <https://orcid.org/0000-0002-7264-4433>
 Helge Heimburg  <https://orcid.org/0000-0002-1532-3190>
 Fernanda Herrera-Mesías  <https://orcid.org/0000-0001-8216-871X>
 Marina Janković Milosavljević  <https://orcid.org/0000-0002-2136-815X>
 Ana Ješovnik  <https://orcid.org/0000-0002-4514-1478>
 Giorgos Karlis  <https://orcid.org/0000-0003-4171-9444>
 Max Kasperek  <https://orcid.org/0000-0002-5604-6791>
 Anikó Kovács-Hostyánszki  <https://orcid.org/0000-0001-5906-4816>
 Michael Kuhlmann  <https://orcid.org/0000-0003-3664-6922>
 Romain Le Divelec  <https://orcid.org/0000-0002-0759-0344>
 Laura Likov  <https://orcid.org/0000-0002-7215-1006>
 Jessica Litman  <https://orcid.org/0000-0003-2481-5709>
 Toshko Ljubomirov  <https://orcid.org/0000-0002-3202-3309>
 Henning Bang Madsen  <https://orcid.org/0000-0003-2542-3109>
 Leon Marshall  <https://orcid.org/0000-0002-7819-7005>

Libor Mazánek  <https://orcid.org/0000-0003-0150-3681>
 Dubravka Milić  <https://orcid.org/0000-0002-8828-1489>
 Maud Mignot  <https://orcid.org/0000-0002-4674-1811>
 Sonja Mudri-Stojnić  <https://orcid.org/0000-0002-0118-0475>
 Andreas Müller  <https://orcid.org/0000-0002-8322-1292>
 Zorica Nedeljković  <https://orcid.org/0000-0001-7645-4453>
 Petar Nikolić  <https://orcid.org/0000-0002-1280-8627>
 Frode Ødegaard  <https://orcid.org/0000-0002-7686-8610>
 Sebastien Patiny  <https://orcid.org/0000-0003-4583-9902>
 Juho Paukkunen  <https://orcid.org/0000-0001-8587-3035>
 Gerard Pennards  <https://orcid.org/0000-0002-6536-4636>
 Celeste Pérez-Bañón  <https://orcid.org/0000-0002-2228-7773>
 Adrien Perrard  <https://orcid.org/0000-0002-4279-9987>
 Theodora Petanidou  <https://orcid.org/0000-0003-1883-0945>
 Lars B. Pettersson  <https://orcid.org/0000-0001-5745-508X>
 Grigory Popov  <https://orcid.org/0000-0002-2519-1937>
 Snežana Popov  <https://orcid.org/0000-0001-9892-8998>
 Christophe Praz  <https://orcid.org/0000-0003-2649-3141>
 Alex Prokhorov  <https://orcid.org/0000-0002-3367-260X>
 Marino Quaranta  <https://orcid.org/0000-0003-0082-4555>
 Vladimir G. Radchenko  <https://orcid.org/0000-0002-8679-1362>
 Snežana Radenković  <https://orcid.org/0000-0002-7805-9614>
 Pierre Rasmont  <https://orcid.org/0000-0003-0891-2189>
 Claus Rasmussen  <https://orcid.org/0000-0003-1529-6548>
 Antonio Ricarte  <https://orcid.org/0000-0003-2298-981X>
 Stephan Risch  <https://orcid.org/0000-0003-1628-0345>
 Stuart P. M. Roberts  <https://orcid.org/0000-0002-5473-4718>
 Santos Rojo  <https://orcid.org/0000-0003-2160-9643>
 Lise Ropars  <https://orcid.org/0000-0001-7621-2825>
 Paolo Rosa  <https://orcid.org/0000-0003-2919-5297>
 Carlos Ruiz  <https://orcid.org/0000-0002-6873-337X>
 Ahlam Sentil  <https://orcid.org/0000-0001-7118-428X>
 Viktor Shparyk  <https://orcid.org/0000-0003-2054-8279>
 Jan Smit  <https://orcid.org/0000-0001-9249-8739>
 Daniele Sommaggio  <https://orcid.org/0000-0001-9999-3791>
 Villu Soon  <https://orcid.org/0000-0001-5368-0319>
 Axel Ssymank  <https://orcid.org/0000-0002-8285-5429>
 Gunilla Ståhls  <https://orcid.org/0000-0003-0505-0691>
 Jakub Straka  <https://orcid.org/0000-0002-8987-1245>
 Bogdan Tomozii  <https://orcid.org/0000-0001-9095-7612>
 Tamara Tot  <https://orcid.org/0000-0001-8776-9362>
 Leendert-Jan van der Ent  <https://orcid.org/0000-0002-2235-805X>
 Jeroen van Steenis  <https://orcid.org/0000-0001-9231-1516>
 Wouter van Steenis  <https://orcid.org/0000-0002-9072-3370>
 Androulla I. Varnava  <https://orcid.org/0000-0001-5085-0159>
 Nicolas J. Vereecken  <https://orcid.org/0000-0002-8858-4623>
 Sanja Veselić  <https://orcid.org/0000-0002-7613-8052>
 Adi Vesnić  <https://orcid.org/0000-0003-0540-5907>
 Alexander Weigand  <https://orcid.org/0000-0001-7587-6531>
 Bogdan Wisniowski  <https://orcid.org/0000-0001-7101-9233>
 Thomas J. Wood  <https://orcid.org/0000-0001-5653-224X>

Dominique Zimmermann  <https://orcid.org/0000-0002-3075-6752>

Denis Michez  <https://orcid.org/0000-0001-8880-1838>

Ante Vujčić  <https://orcid.org/0000-0002-8819-8079>

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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.

How to cite this article: Reverté, S., Miličić, M., Ačanski, J., Andrić, A., Aracil, A., Aubert, M. et al. (2023) National records of 3000 European bee and hoverfly species: A contribution to pollinator conservation. *Insect Conservation and Diversity*, 16(6), 758–775. Available from: <https://doi.org/10.1111/icad.12680>