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Synthesised database of wild bee and hoverfly records in Europe

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Wild bees (Hymenoptera: Anthophila) and hoverflies (Diptera: Syrphidae), the two major groups of insect pollinators, are undergoing alarming declines worldwide, including Europe. The lack of accessible and verified spatial and temporal occurrence records currently challenges efforts to understand and mitigate this decline. Here, we compiled datasets from diverse sources, including taxonomists, national experts, public repositories, museum collections, published literature, verified open-access platforms, and aggregated datasets from previous European projects. The collected data were standardised, cleaned and validated by taxonomists and national experts. This collective effort resulted in two databases comprising more than 4.34 million and 1.04 million records for wild bees and hoverflies, respectively. The databases cover 97% of the European bee fauna (2,083 species out of 2,138 recorded in Europe) and 97% of the European hoverfly fauna (886 species out of 913 recorded in Europe). These standardised databases constitute essential resources for future assessments of status and trends, habitat associations, and other research and conservation initiatives to protect and understand wild pollinators on the European continent.

Background & Summary

The current rate of biodiversity loss is an unprecedented threat in the history of humanity. The associated loss of ecosystem services is impacting food provision, air and water quality, waste remediation, flood regulation, and the diversity of plants and associated organisms[1]. Pollinators are a key element of this global biodiversity, providing vital pollination ecosystem services to domesticated and wild plants[2]. Among the pollinators that are increasingly threatened by global changes are bees (Hymenoptera: Anthophila) and hoverflies (Diptera: Syrphidae). Two European Red Lists formally encapsulate the worries regarding their conservation status in Europe[3,4]. Altogether, these Red Lists indicate that 17% of the 2,834 assessed species are threatened with extinction, while data is deficient for over 40% of all species. Available national studies suggest an even more alarming situation in some countries — for example, in Belgium, 33% of the assessed bee species were classified as threatened[5], and in the Netherlands, 46% of hoverfly species were assessed as threatened, with the national extinction rate of Syrphidae accelerating dramatically since 2000[6]. At a local scale a decrease of 80% in insect biomass and 65% of species was recorded in Germany and the Netherlands[7,8]. The main identified drivers of decline include habitat destruction and fragmentation, environmental pollution, climate change, species invasion, pesticides and pathogens spillover[9–11].

In response to growing evidence of pollinator declines, the European Union has developed a range of measures — from long-standing biodiversity frameworks to more recent, targeted actions. Foundational instruments such as the Convention on Biological Diversity, the Bern Convention, and EU nature legislation, including the Birds and Habitats Directives (which underpin the Natura 2000 network), remain central to biodiversity conservation, though not originally designed with pollinators in mind. Broader strategies like the EU Biodiversity Strategy, the European Green Deal, the Farm to Fork Strategy, and the newly adopted Nature Restoration Regulation also support pollinators by promoting sustainable land use, ecosystem recovery, and reduced pesticide use. In recent years, targeted initiatives have emerged, including the EU Pollinator Initiative, the revised EU Pollinator Initiative - New Deal for Pollinators[12], interregional projects such as SAPOLL (*SAuvons nos POLLinisateurs*), and EU-funded research and coordination efforts like Life4Pollinators and SPRING. Species-specific action plans have also been developed (e.g.[13–15]). However, only since the adoption of the Nature Restoration Regulation

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(2024/1991) in 2024, with its Article 10, did both EU pollinator conservation and an EU wide Pollinator monitoring become legally binding for EU Member States[16].

Despite the significant progress made in Europe to tackle pollinator decline, conservation efforts are still hampered by considerable knowledge gaps[17]. These gaps include low knowledge of the conservation status, limited predictive abilities regarding the impact of anthropogenic and environmental stressors, lack of taxonomic capacity, and absence of standardised tools for assessing pollinator status and trends[12,18]. The phylogenetic and morphological diversity of insect pollinators, together with their wide variation in body size, mobility, and typically short lifespans, pose substantial challenges for the development and standardisation of robust population monitoring schemes in order to fill those gaps[19]. Additionally, a major challenge for effective pollinator conservation is that data on pollinator distribution are notoriously scattered across numerous European institutions and online platforms (e.g., GBIF and BWARS) making comprehensive assessment and coordinated action difficult. In addition, their quality and quantity vary broadly between regions, with northern and western European countries having good datasets, while southern and eastern European countries present important knowledge gaps[20].

A harmonised occurrence database is a prerequisite for developing a baseline of robust indicators of pollinator status, quantifying population declines, identifying their drivers, and assessing the resulting impacts on society and the economy[21,22]. Verified and harmonised data, alongside spatial mapping, are also essential for guiding the transition towards more targeted, sustainable, and actionable conservation policies, including prioritisation of conservation areas[23], and serve as an efficient instrument to evaluate the progress of European Union conservation and restoration strategies[12]. In this context, the aim of this work is to compile and synthesise available occurrence data on wild bees and hoverflies, providing a consolidated reference database to support future research and inform the development of robust indicators for the status of these key pollinator groups in Europe.

The present work was developed within the framework of multiple EU-funded projects: (i) the "Safeguard" project, initiated by the European Commission under the Horizon-2020 program for research and innovation; (ii) the "ORBIT" and "Taxo-Fly" projects, funded by the Directorate-General for Environment (DG ENV), which aim to centralise and generate taxonomic information (including ecology and distribution) for all the species of bees and hoverflies; (iii) the "Pulse" project, also funded by DG ENV, aiming to update the Red List of European bees; (iv) The European Red List of Hoverflies project, funded by the European Commission, aimed to assess the conservation status of European hoverflies. All these projects ultimately aim to reverse the losses of wild pollinators by joining the efforts of world-leading researchers, NGOs and policy experts. Their common task is delivering the most comprehensive open EU wild pollinator distribution database, a first step in consolidating European bee and hoverfly occurrence data. The next steps should focus on integrating any overlooked datasets, considering additional data sources, including national and regional monitoring programs, unpublished datasets, and contributions from citizen science initiatives. This will help expand the records of European pollinators, improve the representativeness of different groups, and improve knowledge on their abundance and distribution across the continent. To ensure long-term relevance and usability, it is crucial to move beyond a static database and work toward developing a dynamic, continuously updated resource. Thus, following its publication, the Safeguard occurrence databases will be deposited on GBIF, where it will receive a DOI and be maintained through versioned updates. A first update is already planned within the ongoing European project WildPosh[24], and future updates will be released as new versions under the same DOI to ensure continuity and prevent dataset duplication. Although long-term updates are currently project-driven, due to the absence of a permanent European structure dedicated to coordinating regular dataset revisions, the steady funding of pollinator-related European initiatives, the implementation of the EU Nature Conservation Law (i.e., Chapter 10), and the monitoring obligations imposed on Member States are expected to support sustained updating of this resource.

Methods

In the following work, we consider as "data" a record that includes at least the name of the species and the coordinates where the species was observed or collected. A "dataset" refers to a set of data received from each provider, while the term "database" represents the compilation of all the datasets for each pollinator group (bees and hoverflies) into a single, consolidated resource.

All the steps of the data processing workflow are presented in Fig. 1.

Data Collection

***Wild bees* (Hymenoptera: Anthophila).** We explored multiple sources to establish a comprehensive database on European bees. The state of the art was the existing data from BDFGM (*Banque de Données Faunique de Gembloux-Mons*) and previous European projects, which presents the baseline of our database. We then supplemented these data by acquiring extensive and comprehensive records from four main sources: taxonomists with expertise in specific taxa at global level, regional or national experts on bee fauna as well as accessible public platforms and repositories. To address gaps in existing knowledge, especially for data-deficient groups and under-sampled regions, we explored three additional sources: literature, museum and private collections, and newly collected material (Table 1).

The BDFGM is a faunistic database developed through a long-standing collaboration between the Zoology Laboratory at the University of Mons and the Entomology Unit of Functional and Evolutionary Biology at Gembloux Agro-Bio Tech, University of Liège (formerly the Faculty of Agronomy of Gembloux University), which focused mainly on spatial data on wild bees (see http://www.atlashymenoptera.net). The BDFGM has served as a foundational data source for several major initiatives and projects focusing on pollinator monitoring and conservation.

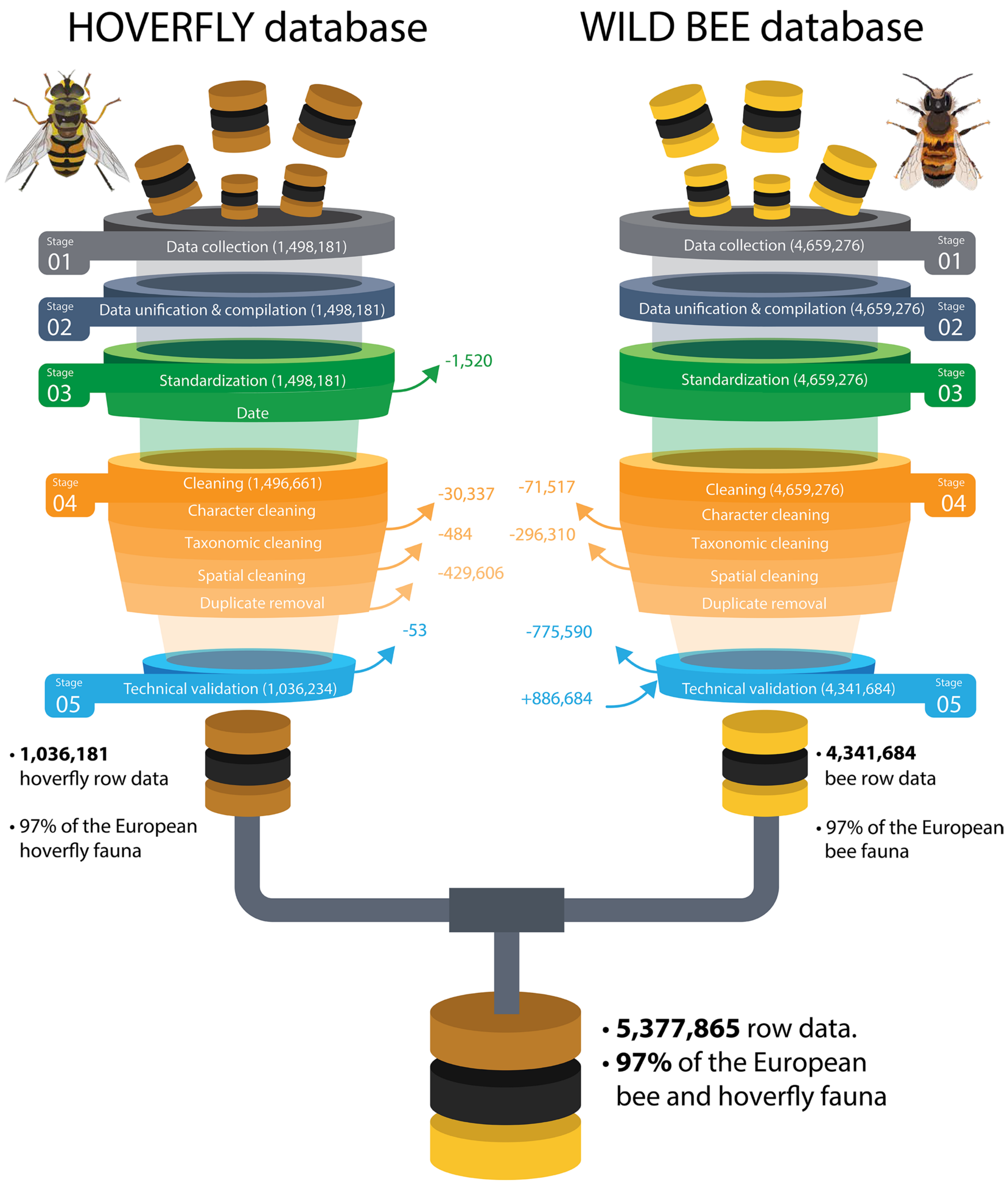

Fig. 1 Summary of the data processing workflow of bees and hoverflies: data collection, data unification and compilation, standardisation, cleaning (character cleaning, taxonomic cleaning, spatial cleaning, and duplicate removal), and technical validation. The numbers in brackets indicate the number of raw data at each processing stage. The numbers outside the funnels indicate the number of raw data removed (preceded by "-") or added (preceded by "+").

The previous projects include the Status and Trends of European Pollinators (STEP project), the Bees, Wasps and Ants Recording Society (BWARS) program, and the SAuvons les POLLinisateurs sauvages (SAPOLL) project. The STEP project was supported by the European Commission under the 7th Framework Programme for Research and Technological Development. STEP compiled a large spatio-temporal dataset on pollinators to assess the extent of their decline, identify the main drivers, and evaluate the consequences for ecosystems and agriculture[2]. SAPOLL is a cross-border initiative funded by the European Regional Development Fund and Wallonia through the INTERREG V France-Wallonie-Vlaanderen program. It aimed to develop an action plan

datasetName	dataAvailability	categoryOfDatasetSource	datasetSource	numberOfRowData	DateOfLastUpdate
Additional_data_PULSE_ SAFEGUARD	published and unpublished data	Different sources	UMONS	22754	—
Literature_Andrena	published data	Literature	see list of references in metadata_2[47]	453	20231016
Literature_Belarus	published data	Literature	Reverté, Miličić *et al.*[28]: https://doi.org/10.1111/icad.12680	338	20230900
Literature_Ebmer_ Halictus	published data	Literature	see list of references in metadata_2, Sentil *et al.*[47]	777	—
Literature_Moldova	published data	Literature	Reverté, Miličić *et al.*[28]: https://doi.org/10.1111/icad.12680	217	20230900
Literature_Russia	published data	Literature	see list of references in metadata_2[47]	8921	20230226
Literature_Russia2	published data	Literature	see list of references in metadata_2[47]	6320	20230901
Grandi_Collection	unpublished data	Museum/historical collection	Lucia Lenzi & Fabio Sgolastra	5392	20230331
Linz_Museum	unpublished data	Museum/historical collection	UMONS	7423	20221228
NHMW_Museum	unpublished data	Museum/historical collection	Dominique Zimmermann	3192	20221200
Priore_Collection	unpublished data	Museum/historical collection	UMONS	3158	20230828
Sapienza_Museum	unpublished data	Museum/historical collection	Maurizio Mei	6743	20230223
BoguschP_CzechRepublic	unpublished data	National expert	Petr Bogusch	6348	20220519
BurdysE_Lithuania	unpublished data	National expert	Eduardas Budrys	3215	20230131
CasalM_MelittidaeSpain	unpublished data	National expert	Mercè Galbany Casal	40	20230831
DemeterI_Romania	unpublished data	National expert	Demeter Imre	602	20190000
EIS_Netherlands	unpublished data	National expert	European Invertebrate Survey (EIS) the Netherlands, Leiden	344572	20221122
FiordalisoW_Belgium	unpublished data	National expert	William Fiordaliso	4752	20221021
FlaminioS_Italy	unpublished data	National expert	Simone Flaminio	541	20231212
GasparH_Portugal	published data	National expert	Gaspar *et al.*[29]: https://www.researchgate.net/publication/367328436_New_regional_contributions_to_the_knowledge_of_the_portuguese_bee_fauna_Hymenoptera_Anthophila	901	20221200
KieratJ_Poland	unpublished data	National expert	Justyna Kierat	40	20230828
PetanidouT_Greece	unpublished data	National expert	Theodora Petanidou	13669	20230510
RuizC_ MelittidaeCanaryIslands	unpublished data	National expert	Carlos Ruiz Carreira	59	20230729
SelisM_Italy	unpublished data	National expert	Marco Selis	1942	20220930
StojnicS_Serbia	unpublished data	National expert	Sonja Mudri Stoni	4183	20220900
VarnavaA_Cyprus	published data	National expert	Varnava *et al.*[29]: https://zookeys.pensoft.net/article/38328/download/suppl/31/	458	20220410
VesnicA_Bosnia	unpublished data	National expert	Adi Vesnic	459	20230228
YvesP_Corsica	unpublished data	National expert	Giberrnau Marc and Maestracci Pierre-Yves	33	20230629
BenrezkallahJ_Cyprus	unpublished data	Newly collected material	UMONS	211	20230125
deManincorN_Greece	unpublished data	Newly collected material	UMONS, de Manincor[31], https://doi.org/10.5281/zenodo.17135537	4213	20250303
DevorsineR_Italy	unpublished data	Newly collected material	UMONS	351	20230906
GambarottoM_Belgium	unpublished data	Newly collected material	UMONS	910	20230906
ThulierJ_Peyresq	unpublished data	Newly collected material	UMONS	687	20230906
Artportalen_Sweden	published data	Open data	Artportalen: https://www.artportalen.se/Occurrence/TaxonOccurrence/16/2002991	283302	20220412
ArtsDataBanken_Norway	published data	Open data	ArtsDataBanken: https://artskart.artsdatabanken.no/	117261	20220320
BiodiversityMaps_Ireland	published data	Open data	Biodiversity Maps[32]: https://maps.biodiversityireland.ie/Dataset/5	50902	2022
BWARS	published data	Open data	BWARS (Bees, Wasps & Ants Recording Society 2022): https://bwars.com/sites/default/files/diary_downloads/20230404%20BWARS%20public%20data.zip	491891	2022
FinBIF_ AmateurEntomologist_ etc_Finland	published data	Open data	FinBIF: https://laji.fi/en/observation/map?target=MX.289375&collectionId=HR.22	55030	20220325
Continued					

datasetName	dataAvailability	categoryOfDatasetSource	datasetSource	numberOfRowData	DateOfLastUpdate
FinBIF_LUOMUS_ Finland	published data	Open data	FinBIF: https://laji.fi/en/observation/map?target=MX.289375&countryId=ML.206&collectionId=HR.3778,HR.1989,HR.3552,HR.3551,HR.1247,HR.1627,HR.1127,HR.1207,HR.121,HR.1915,HR.3811,HR.4171	98476	20230325
GBIF_Estonia	published data	Open data	GBIF: see list of sources in metadata_3, Sentil *et al.* 2025	39480	20220706
GBIF_Switzerlands	published data	Open data	GBIF[33]: https://doi.org/10.15468/ksfmzj	432492	2022
mdataMNHN_ Luxembourg	published data	Open data	mdata.MNHN: https://mdata.mnhn.lu/	10006	20220321
Zenodo_Iberia	published data	Open data	Bartomeus *et al.*[34]: https://doi.org/10.5281/zenodo.6354502	71374	20221018
Zobodat_Austria	published data	Open data	Zobodat: https://www.zobodat.at/belege.php	13251	20220802
SAPOLL	unpublished data	Previous project	UMONS	197589	20230400
BDFGM_Andrenidae	unpublished data	Previous project	UMONS	592912	20230400
BDFGM_Anthophorini_ Melectini	unpublished data	Previous project	UMONS	100971	20230116
BDFGM_Bombus	unpublished data	Previous project	UMONS	754797	20231211
BDFGM_Halictidae	unpublished data	Previous project	UMONS	241252	20230400
BDFGM_Megachilidae	unpublished data	Previous project	UMONS	127526	20230400
BDFGM_Melittidae	unpublished data	Previous project	UMONS	24987	20230400
CalafatJD_BalearicIslands	unpublished data	Private data	Joan Díaz Calafat	2912	20230127
CappellariA_Italy	unpublished data	Private data	Andree Cappellari	12044	20231117
JansenK	unpublished data	Private data	Kobe Janssen	1742	2022
KleijnD_Boshommel	unpublished data	Private data	David Kleijn	8784	20221000
KleijnD_Netherlands	unpublished data	Private data	David Kleijn	1403	20221000
ScheperJ_France	unpublished data	Private data	Jeroen Scheper	4385	20221200
ULB_CanaryIslands	unpublished data	Private data	Leon Marshall	410	20220705
BoguschP_Coelioxys	unpublished data	Taxonomist	Petr Bogusch	567	20221213
BoguschP_Cuckoobees	unpublished data	Taxonomist	Petr Bogusch	11164	20220307
BoguschP_Dioxyini	unpublished data	Taxonomist	Petr Bogusch	15	20221213
DatheH_Hylaeus	unpublished data	Taxonomist	Holger Dathe	29312	20211031
GadoumS_Hylaeus	unpublished data	Taxonomist	Serge Gadoum	6497	20230216
KasparekM_Anthidiini	unpublished data	Taxonomist	Max Kasparek	1036	20220611
KulmannM_Colletes	unpublished data	Taxonomist	Michael Kuhlmann	8162	20231208
MichezD_Melittidae	unpublished data	Taxonomist	UMONS	14	20230924
MullerA_Osmiini	unpublished data	Taxonomist	Andreas Muller	14150	20220412
RadchenkoV_Colletes	unpublished data	Taxonomist	Radchenko Vladimir	332	20210101
RadchenkoV_Dasypoda	unpublished data	Taxonomist	Radchenko Vladimir	172	20210101
RischS_Eucera	unpublished data	Taxonomist	Stephan Risch	11302	20220629
SmitJ_Nomada	unpublished data	Taxonomist	Jan Smit	50903	20220400
StrakaJ_Nomada	unpublished data	Taxonomist	Jakub Straka	3211	20220418
WoodTJ_Andrena	unpublished data	Taxonomist	Thomas James Wood	15541	20220800
WoodTJ_Panurginae	unpublished data	Taxonomist	Thomas James Wood	253	20231121

Table 1. Overview of the bee datasets included in this study, with information on the dataset name, availability (published or unpublished), source category (e.g., literature, museum, national expert), specific source, number of raw data records, and date of last update.

for wild pollinators in Belgium and northern France. One of the project's objectives was to create a shared database of bees and hoverflies[25]. BWARS is a UK-based organisation, operating under the aegis of the UK Biological Records Centre. It is dedicated to studying and conserving bees, wasps, and ants (Hymenoptera) to promote the recording and understanding of these insect groups[26]. The datasets produced and compiled by these projects provided a range of information, including the spatio-temporal distribution of European bees.

We acquired 16 datasets from 12 taxonomists, covering most of the main bee clades recorded in Europe: Melittidae (Denis Michez and Vladimir Radchenko), Eucerini (Stephan Risch), *Nomada* (Jan Smit and Jakub Straka), *Sphecodes, Ammobates, Ammobatoides, Biastes, Chiasmognathus, Epeoloides, Parammobatodes, Pasites, Schmiedeknechtia, Epeolus, Coelioxys, Dioxys, Metadioxys* and *Paradioxys* (Petr Bogusch and Jakub Straka), Osmiini (Andreas Müller), *Andrena* and Panurginae (Thomas James Wood), *Hylaeus* (Holger H. Dathe and Serge Gadoum), Anthidiini (Max Kasparek) and *Colletes* (Michael Kuhlmann and Vladimir Radchenko). Additionally, 16 datasets from national and local experts across various European countries were obtained:

Czech Republic (Petr Bogusch), Lithuania (Eduardas Budrys), Spain (Mercè Galbany Casal), Romania (Demeter Imre), Belgium (William Fiordaliso), Italy (Marco Selis and Simone Flaminio), Portugal (Hugo Gaspar), Poland (Justyna Kierat), Greece (Theodora Petanidou), The Netherlands (Menno Reemer, European Invertebrate Survey EIS), Canary Islands (Carlos Ruiz Carreira), Serbia (Sonja Mudri Stojnić), Cyprus (Androulla Varnava), Bosnia and Herzegovina (Adi Vesnić) and Corsica (Gibernau Marc and Maestracci Pierre-Yves). In some countries, centralised national datasets have already been made publicly accessible through: (i) repositories: Zenodo (the Iberian Peninsula), (ii) National platforms: Zobodat (Austria), Artportalen (Sweden), FinBIF (Finland), ArtsDataBanken (Norway), mdata MNHN (Luxembourg), Biodiversity Maps (Ireland), and (iii) international platforms: Global Biodiversity Information Facilities GBIF (Estonia and Switzerland) (Table 1, metadata 1[26]).

For some target genera (*Andrena* and *Halictus*) and countries (Russia, Belarus and Moldova) for which we did not have enough records from the previous sources, we digitised part of the available literature, following the recommendations of expert taxonomists (see the list of references in metadata 2[26]).

Historical collections were also used as sources of data. We digitised information from voucher specimens housed in five European museums, including the *Oberösterreichisches Landesmuseum* (Linz, Austria), the Sapienza University of Rome Museum of Zoology (Rome, Italy), the Natural History Museum of Vienna NHMW (Vienna, Austria), the Priore historical collection hosted by the University of Naples Federico II (Naples, Italy), and the Guido Grandi Collection at the University of Bologna (Italy). Data from many museums had already been included in the STEP dataset as part of taxonomic revisions (e.g.[27]). The selection of museums was guided by the taxonomic expertise of the co-authors on the diversity and originality of the collections (e.g., number of species and rarity), the accessibility of the material, as some European museums offer limited access, and the accuracy of specimen identifications (i.e., collections that had recently undergone taxonomic revision). Considering limited time and resources, material from data deficient species or less studied regions was prioritised for encoding.

Lastly, we targeted some Southern European countries, particularly Italy, Greece and Cyprus, where significant gaps in occurrence data were identified[28]. Field trips were organized in collaboration with taxonomists to address these gaps and collect new material from these under-sampled areas. This category (i.e., newly collected material) also includes two datasets from Belgium and France that were collected by the UMONS team throughout the Safeguard project period.

Through the exchanges we had with experts, we gained access to seven additional private datasets (Table 1).

We considered that enough data had been collected for a species when taxonomists, national and regional experts, confirmed during maps' validation that the available records represented the distribution of the target species.

Hoverflies. Regarding hoverflies, two projects have significantly contributed to compiling spatial data. The first is the European Red List of Hoverflies (EU and pan-Europe), the first assessment of the conservation status of European hoverflies. This project gathered and validated a large amount of spatial data and also highlighted gaps and geographical biases in the data. The second is the EU funded Service Contract 'Taxonomic Resources for EU Pollinator Monitoring Schemes (2 Lots), Lot 2 - Development of Taxonomic Tools for Hoverflies (Insecta, Syrphidae) (Taxo-Fly)', which focused on compiling accurate taxonomic, occurrence and ecological data on European hoverflies. Furthermore, the STEP project provided a certain quantity of data related to hoverflies.

Similar to the approach used for bees, the core hoverfly database was expanded by integrating extensive and detailed records obtained from taxonomists specialising in particular hoverfly taxa, experts with regional or national knowledge of hoverfly fauna, publicly accessible platforms and biodiversity repositories, and institutional databases. We incorporated additional data from published literature, entomological collections housed in museums and private holdings, and recently gathered field material.

IUCN Red List Assessors compiled part of the data included in this work: Andrea Aracil, Ana Grković, Antonio Ricarte, Axel Ssymank, Anja Šebić, Ante Vujić, Celeste Pérez Bañón, Dubravka Milić, Gerard Pennards, Gunilla Ståhls, Jeroen van Steenis, Laura Likov, Leendert-Jan van der Ent, Libor Mazánek, Marija Miličić, Marina Janković, Rita Földesi, Santos Rojo, Sanja Veselić, Snežana Radenković, Tamara Tot, Zorica Nedeljković and Wouter van Steenis. Some of these data records were already included in the previous projects (e.g., STEP), but many records were newly collected in the framework of this project.

Historical collections were also valuable sources of data for Syrphidae. Data from several museums visited over the years (visits undertaken in the context of other research objectives) have been digitised and deposited in the FSUNS database (see the list of museums and historical collections in metadata 2[26]).

Regarding field trips, research efforts focused on areas known for their high species richness (e.g., Greece and Spain), as these regions are believed to host species that are either new to science or to Europe.

The nature of the contributed data varied considerably across sources. The IUCN assessment relied on datasets compiled by assessors from published literature and their own private databases, while Taxo-Fly brought together additional occurrence information from a wide range of sources and systematised these records for taxonomic use. Earlier material generated during the STEP project also contributed to the dataset. These project-based datasets were complemented by expert-contributed files, publicly accessible biodiversity platforms such as GBIF and FinBIF, digitised material from historical museum collections, and newly gathered field records from regions of high species richness. Because these sources differ in scope and content, their proportional contributions are not summarised here; the origin of each individual record is preserved in the database and can be directly identified by users. The present project integrates all of these inputs into a single harmonised database[29–34].

Data unification and compilation

A thorough exploration of the datasets was conducted to gain a general insight into their contents and formats before the standardisation and cleaning process. Based on this, we developed a data template, which defines the structure of our databases by specifying field names (i.e., column names) and their expected values or formats. To ensure compatibility with existing standards referenced in Simon Delso, *et al.*[35] and to adhere to FAIR

(Findable, Accessible, Interoperable, and Reusable) principles[36], we developed the "Pollinator Core" template. This template aligns with Darwin Core where applicable. However, Darwin Core is a general-purpose biodiversity standard and does not cover all the data elements required for pollinator monitoring, such as *datasetProvider, datasetSource*, *dataSource*, *individualCountInterval* and *startIndividualCount*, *endIndividualCount*. The standards compiled in the Pollinator Metadata Standard[35], extend Darwin Core with additional terms. Our "Pollinator Core" follows this approach, incorporating Darwin Core and Pollinator Metadata Standard terms and additional fields needed to capture the full scope of our database. Table 2 presents the fields of the template. The file metadata 3[26] describes the template fields and provides a mapping between their names and the existing standards.

The contents of the bee datasets were placed separately in the standardised template, and then merged into one unique database.

For hoverflies, the initial step involved merging all datasets to retain relevant information into FileMaker Pro[37], a cross-platform relational database application. It integrates a database engine with a graphical user interface (GUI) and security features, allowing users to visually modify a database. It supports the use of sub-databases, which are essentially related tables within a main database, enabling users to structure and organise their data efficiently. These sub-databases are linked through relationships, allowing for easy access to related information. Additionally, FileMaker Pro incorporates calculations (for calculation details see metadata 4[26]), which can be used to automate tasks, perform mathematical operations, or manipulate data dynamically within fields, layouts, and scripts. A dedicated database was developed to integrate all separate datasets (including complete information provided from each source). Most data wrangling was carried out within this platform. Four sub-databases were created - covering dates, specimen sex, species names, and presence in Europe based on Reverté, Miličić, *et al.*[28] - as detailed later in the text. In certain instances, the original information was retained as is and incorporated into the final database (e.g., nearest place and locality, included in verbatimLocality). However, the majority of variables underwent transformation, involving multiple calculations to standardise and clean the data. Only data that met all predefined criteria—such as valid species names, valid dates, valid geographic coordinates, and confirmed presence in Europe according to Reverté, Miličić, *et al.*[28]—were included in the final database presented in this study. Clean hoverfly datasets contained following fields: Collection, Code, Genus, Species, Genus_Species, Country, Nearest place, Locality, Latitude, Longitude, Collector, Date_Start_original, Date_End_original, Starting_day, Starting_month, Starting_year, Ending_day, Ending_month, Ending_year, Source, Data_provider, without_year (Boolean, true/false), which were then mapped to Pollinator Core template, same as for wild bees.

Because the two databases were prepared independently, each team relied on the tools and workflows they had already established, which explains the differences in software used. Nevertheless, the objectives and the final outputs were fully harmonized.

Data Standardisation

Coordinates. *Georeferencing.* We collected data both with and without geographical coordinates. When records lacked original coordinates, but included locality descriptions that clearly referred to a single identifiable place (e.g. city name), we inferred the coordinates by locating and verifying the site using standard digital mapping resources. Information on whether coordinates were provided originally or added manually is available in the "manualGeoreferencing" field in both databases.

For bees, localities were classified into two categories: those with clear spatial extents and those with undefined boundaries. We considered a locality to have undefined boundaries when its limits are not mapped (e.g. regions). We determined the boundaries for localities with well-defined spatial extents by drawing an imaginary polygon encompassing the locality. For localities with undefined boundaries, we estimated the boundaries by identifying and including features of similar type and size (i.e., localities that share the same characteristics, such as forests or protected areas). Once the boundaries were established, we obtained the coordinates of the centroid of the polygon.

For hoverflies, two different approaches were used when coordinates were unavailable. For well-documented localities that have been consistently studied over the years, we assigned coordinates from the FSUNS database, an institutional repository compiling locality information from previous research projects, expert surveys, and published sources, selecting those known to be accurate and reliably associated with the respective locality. These coordinates correspond to previously verified records bearing the same locality name. For localities that had not been previously investigated, we used the locality name as a reference and identified the nearest ecologically meaningful site, such as a park, forest edge, or other natural or semi-natural area. The coordinates of this nearby area were then assigned to the record.

Google Maps[38] was used as a source of coordinates for both bees and hoverflies. All coordinates were recorded using the WGS 1984 geographic coordinate system.

Considering the large number of non-georeferenced records, we prioritized georeferencing for data-deficient groups and poorly studied regions. The remaining non-georeferenced records were excluded but will be explored in future projects.

Coordinates' conversion. The original geographic coordinates were presented in various formats: decimal degrees (DD), degrees minutes and seconds (DMS), and degrees decimal minutes (DDM). First, we identified the format of each set of coordinates. We considered the DD format in our data due to its widespread usage, its scientific format and global applicability. After identifying the formats, we automatically converted the other coordinate formats to DD in Excel or R using custom functions and the conversion formula ($DD = DD + MM/60 + SS/3600$). For hoverflies, the conversion was done with the help of a calculation field for the coordinate conversion within FileMaker Pro ($DD = DD + MM/60 + SS/3600$).

Field	Description
databaseName	Name of the database that includes data on bees or hoverflies.
institutionName	Name of the institution in charge of data management.
projectSource	Name of the projects that have funded the curation process.
projectUpdate	Year of the last database update.
datasetName	Name of the dataset.
datasetProvider	The entity or person who shared or made available the dataset for this project.
datasetSource	Entity or person who originally produced or generated the dataset.
dataSource	Entity or person who produced the data.
license	Creative Common License provides information concerning official permission to use the database.
occurrenceID	A new unique identifier number that was assigned to each data.
verbatimOccurenceID	The original unique identifier of the data.
scientificNameAuthorship	Author credited for the description of the species (scientificName) and the year of publication.
order	Name of the order to which the species belongs.
family	Name of the family to which the species belongs.
subfamily	Name of the subfamily to which the species belongs.
tribe	Name of the tribe to which the bee species belongs. For hoverflies, we did not use tribes since it is currently undergoing substantial changes.
genus	Name of the genus to which the species belongs.
subgenus	Name of the subgenus to which the species belongs.
infraspecificEpithet	Scientific name of the infraspecific epithet, which corresponds to the third part of the scientific name, is used to classify a rank below speci
scientificName	Full binomial name of a species, consisting of a combination of the genus name and the specific epithet.
individualCountInterval	Indicates if an individual count interval occurred (between startIndividualCount and endIndividualCount). If the interval occurred is TRUE other
startIndividualCount	Minimum number of individuals recorded, used when a range is provided to indicate uncertainty in the count.
endIndividualCount	Maximum number of individuals recorded. If no range is specified, endIndividualCount is used as the default.
sex	Sex of the individual(s) represented in the data.
eventDateInterval	Indicates if a sampling interval occurred (between startEventDate and endEventDate). If the interval occurred is TRUE otherwise FALSE.
startEventDate	Starting date of the interval during which the record was done, used when a range is specified to indicate the earliest possible date of the eve
endEventDate	Ending date of the interval during which the record was done. If no range is specified, endEventDate is used by default.
startDay	Earliest day of the interval during which the record was done, used when a range is specified.
startMonth	Earliest month of the interval during which the record was done, used when a range is specified.
startYear	Earliest year of the interval during which the record was done, used when a range is specified.
endDay	Latest day of the interval during which the record was done. If no range is specified, endDay is used by default.
endMonth	Latest month of the interval during which the record was done. If no range is specified, endMonth is used by default.
endYear	Latest year of the interval during which the record was done. If no range is specified, endYear is used by default.
country	Name of the country where the record was observed or collected.
stateProvince	Name of the next smaller administrative region than the country (state, province, canton, department, region, etc.) in which the event occurs.
county	Name of the next smaller administrative region than stateProvince (county, shire, department, etc.) in which the event occurs.
verbatimLocality	Original textual description of the place.
decimalLatitude	Geographic latitude (in decimal degrees) of the data, based on the WGS 1984 geographic coordinate reference system. Positive values are north of
decimalLongitude	Geographic longitude (in decimal degrees) of the data, based on the WGS 1984 geographic coordinate reference system. Positive values are east of
coordinateUncertaintyInMeters	The maximum horizontal distance (in meters) representing the uncertainty around the provided coordinates.
manualGeoreferencing	Indicates whether the coordinates in the bee and hoverfly databases were originally provided in the datasets or manually georeferenced by our te
isPseudodata	Indicates records for which coordinates are not directly tied to individual specimens (see "Pseudodata" section for more details). If a record i
verbatimElevation	The original elevation (altitude, usually above sea level) of the verbatimLocality.

Table 2. Description of the fields included in the template of the bee and hoverfly databases.

Sex. Since the sex of the specimens was recorded in various formats (e.g., male, M, ♂, or in languages other than English), we standardised the information by reducing it to three main characters: M for males, F for females and M&F for both (records that includes both males and females). In the bee database, additional characters were: G (gynandromorph: specimens that have externally features of both sexes); Q (queen) and W (worker). For the hoverfly database a sub-database was created in FileMaker Pro to standardise the information. If the sex was unknown, the data record was marked as "NA".

Number of specimens. For bees, we extracted all non-Arabic numerical values, including ranges, textual descriptions, and Roman numerals. Using this extraction of unique values, we created a dictionary that mapped the original values to their corresponding Arabic numerical values. For data presented as intervals, we split the information into two separate columns: one for the minimum value and one for the maximum value. If only one value was provided, it was recorded in the maximum value column. We then integrated the new numerical values using the created dictionary and the left_join function from the 'dplyr' package[39]. The invalid values were replaced with 1. A similar procedure was applied to the hoverflies within FileMaker Pro, with the added step of extracting information from the sex column. Data providers sometimes reported sex and specimen counts together (e.g., "32 males, 12 females"), which required additional processing. These numbers were extracted and added to the "number of specimens" column. If only one sex and its count were reported, that number was used directly. When counts for both sexes were provided, and the exact numbers of males and females were known, the total number of specimens was calculated as their sum.

Geographical assignment. We assigned the current country, stateProvince and county name to all data using the function st_intersection from the package 'sf'[40,41]. This function assigns administrative divisions by overlaying the geographic coordinates of each occurrence with shapefiles that define the corresponding administrative boundaries.

Coordinate uncertainty. Similar to the number of specimens, the non-Arabic numerical values of precision were extracted. We created a dictionary to map the original precision values to their corresponding new Arabic numerical values (in meters). For precision data presented as intervals, we split the range into two separate columns: one for the minimum value and one for the maximum value. If only one value was provided, it was recorded in the maximum value column. We then integrated the new precision values using the dictionary and the *left_join* function from the 'dplyr' package[39]. The original precision field was subsequently excluded from the database, and unreasonable values (e.g., negative numbers, extremely large distances) were replaced with "NA". For hoverflies, no information on precision was available.

Date. For bees, dates were recovered when accurate date events were provided. Illogical or invalid dates that fell outside acceptable ranges, such as a year after the present year, a day greater than 31, or a month greater than 12, were omitted from the database. Various date formats (e.g., YYYY/MM/DD, YYYY-MM-DD, YY-MM-DD, DDMMYYYY, DD/MM/YYYY, DD-MM-YYYY, DD-MM-YY, DD.MM.YYYY, YYYY-MM, YY-MM, YYYY/MM) were standardised to the YYYY-MM-DD, in accordance with the ISO 8601–1:2019 standard. Due to the substantial differences in date formats, we conducted date inspection and cleaning automatically whenever possible, and manually in cases where automation was not applicable. When dates were displayed as intervals (e.g., "2024/07/25–29"), we split these intervals into two fields: the starting date and the ending date. If only one date was provided, the date was duplicated and the presence/absence of an interval is indicated in the eventDateInterval field.

January 1st and December 31st are sometimes used as placeholders for startEventDate and endEventDate within the same record when only the year of collection is known, which may affect phenology studies. To address this issue, we replaced the day and month with "NA" for records with YYYY-01-01 and YYYY-12-31 as a start date and end date (7463 records), respectively.

Cleaning

Characters cleaning. Initially, we standardised all columns to the Latin-1 format when importing the datasets. We then replaced special characters, including "?" and various unicode whitespace characters, that could have caused issues during database importation in R. Subsequently, we cleaned the data using the mutate() and gsub() functions from the 'dplyr' package in R[39].

Taxonomic cleaning. Species name validation was done in two steps: first, we created the taxonomic backbone with the most up-to-date bee and hoverfly taxonomy, and then we proceeded with the taxonomic cleaning.

For bees, we used the most recent European checklist, which counts 2,138 species[42]. We used the EU checklist to replace the junior synonyms with the accepted senior synonyms. We then prepared a second list (hereafter called "wild bee taxonomic dictionary") of species names where we compiled all other types of mistaken names, such as names with typos, wrong spaces, orthographic variants, other misspellings, and old synonyms. This wild bee taxonomic dictionary has been reviewed and corrected by expert taxonomists in the coauthorship list to make sure it has the most updated species names. Finally, the two lists, the European checklist and the wild bee taxonomic dictionary, have been merged into one final list.

The bee taxonomic cleaning was done in R using a two-match process: (i) first, we matched and replaced all invalid species names (e.g. misspellings, synonyms) that were present in the bee database, with their valid scientific names present in the final list (i.e., the EU checklist of wild bees and the wild bee taxonomic dictionary); (ii) secondly, species names that were not verified and replaced during the first match, have been checked using a fuzzy search approach. This approach used the European checklist as a backbone and matched the uncorrected

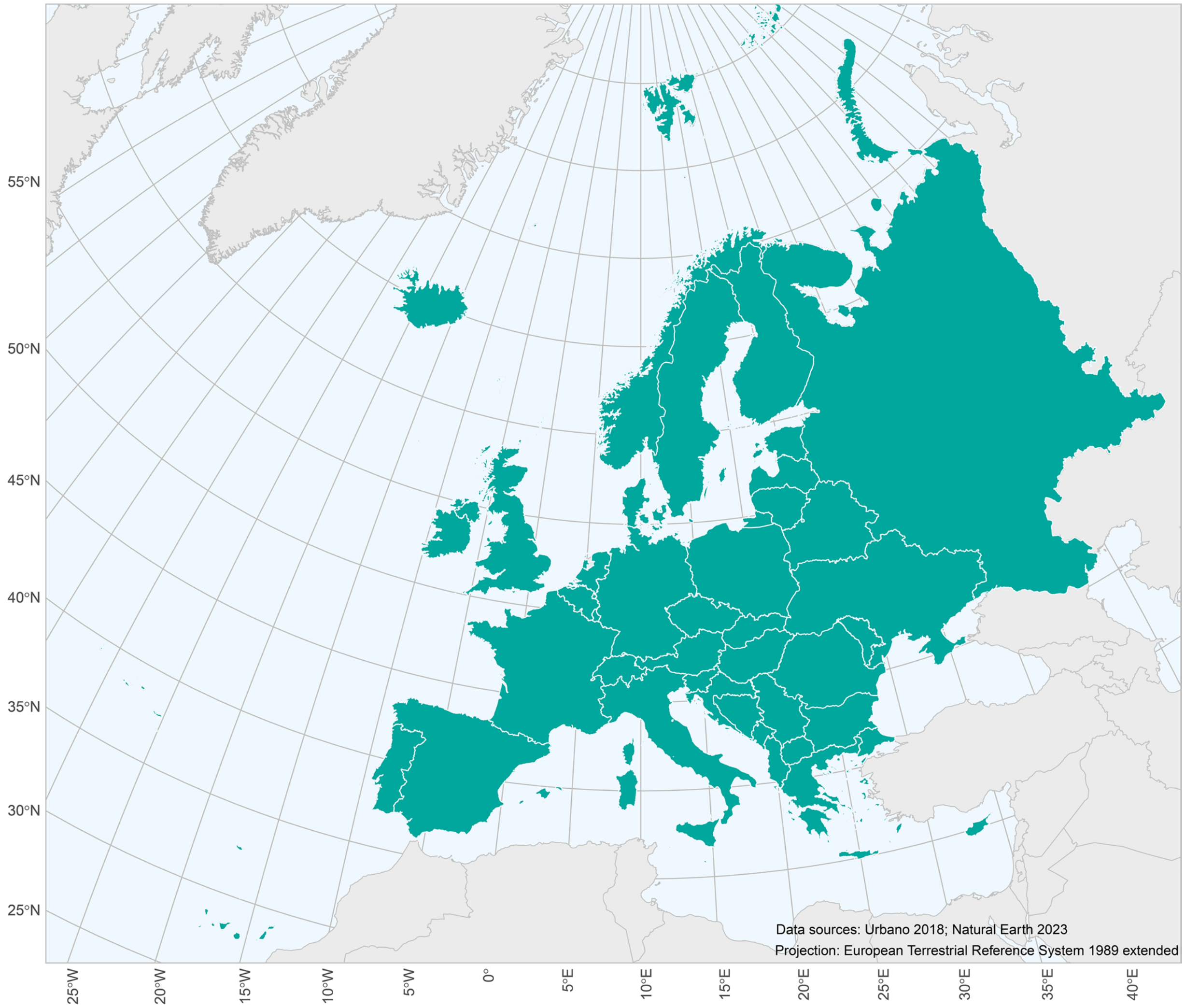

Fig. 2 Map of Europe showing the geographical framework of the compiled database of bees and hoverflies (based on Ghisbain, Rosa, *et al.*[42] and Reverté, Miličić, *et al.*[28]).

species names to it using the stringdist_join function in the R package 'fuzzyjoin'[43,44], that assigned a likelihood score using the Jaro-Winkler distance method. This helped us to manually correct the most likely names, i.e. species names that had a likelihood score below 0.2. Records with wrong or incomplete names (e.g., resolved at the Genus or Family level) have been deleted from the aggregated database (71,517 data).

For hoverflies, we used the species list published in Reverté, Miličić, *et al.*[28], which counts 913 species. Similar to the bee database, a taxonomic dictionary was created for hoverfly names, addressing misspellings, synonyms, blank spaces, and other issues (referred to as the 'hoverfly taxonomic dictionary'). This hoverfly taxonomic dictionary was used to clean and standardise species names and replace them with valid hoverfly nomenclature. Entries with incorrect or incomplete species names were removed (30,337 data). The taxonomic cleaning of the hoverfly database was conducted in FileMakerPro.

These dictionaries are "static" in time and do not take into account the variable use of names over time, and also the variable use of names by region. Because names are sometimes used in a *sensu auctorum* (i.e. in a way that is not consistent with the type material), a straightforward taxonomic dictionary will not capture uses that deviates from a chresonomic framework. In these cases, consultation with taxon authorities is required to ensure data quality. For example, the use of "*Andrena trimmerana*" from 1802–1917 is different from its use after 1917, and between 1917–2022 the use of this name in the published literature and in specimen datasets has also been variable and inconsistent. However, when possible and necessary, these changes in names have been taken into account during the data validation process (see paragraph "Technical validation" below) and ambiguous records have been either deleted or have been assigned to another taxon during the distribution map revision with experts.

Nevertheless, for the synonyms cleaning, we strongly encourage referring to the most up-to-date taxonomic literature. These dictionaries are still useful in the taxonomic cleaning process when manipulating large amounts of records, particularly in relation to the correction of species names typos, misspelling and incomplete names that could not have been cleaned otherwise.

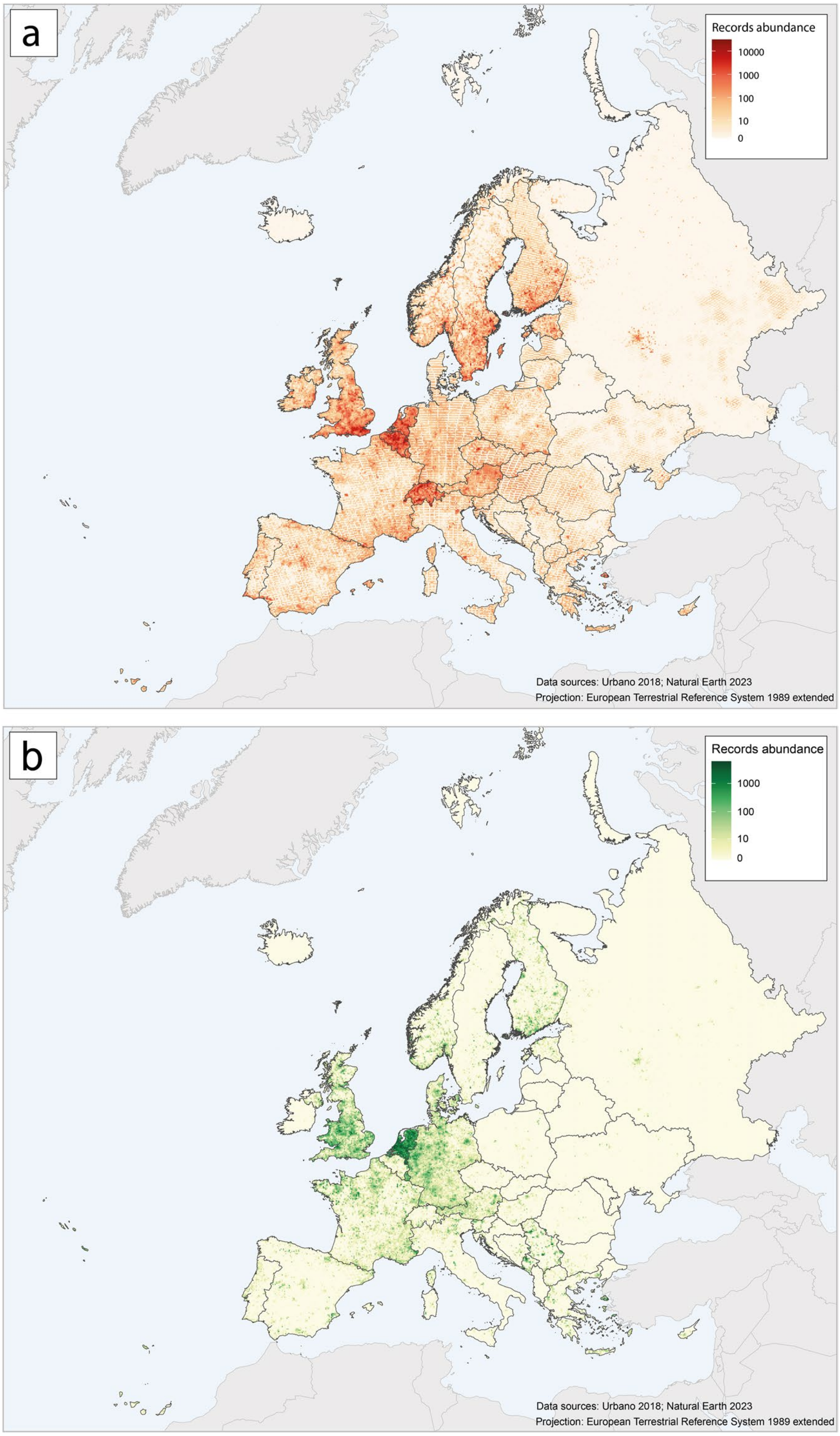

Fig. 3 Map of Europe showing the spatial distribution of data for (**a**) bees and (**b**) hoverflies at a 10 km grid cell.

Spatial cleaning. The geographical range considered for the spatial cleaning is based on the IUCN Red List for geographical Europe and for the 27 Member States of the European Union (EU27) (detailed discussion on the European borders is given in Rasmont, *et al.*[45] (Fig. 2). This geographic range included continental Europe, extending from Iceland and the Azores Islands in the west to the Urals in the east, and from Franz Josef Land in the north to the Canary Islands in the south. The United Kingdom is also included at the geographical Europe level. The Caucasus region is not included, along with the Russian Northern Caucasus. The European part of Türkiye is included, but not the Asian part.

Records with spatial issues were deleted from the final database using the following conditions: (i) data without coordinates, (ii) data with incomplete coordinates, (iii) data with coordinates that fall outside the IUCN shape file described above for Europe, which included non-European data and data that fall into the water (e.g., sea or lakes), and (iv) only for hoverflies, data for which presence was not reported in the country records list[28].

After the spatial cleaning, 296,310 records for bees and 484 records for hoverflies have been removed.

Duplicate removal. One of the first steps in data cleaning for hoverflies was removing duplicates. Duplicates came from overlapping sources, for example, parts of the FSUNS hoverfly database had been used in previous works, including IUCN assessments, and additional records were retrieved from external repositories such as GBIF, where some contributors had already deposited their data.

When two data in the initial datasets had exactly the same locality name, coordinates, date, combination of sex and number of specimens, they were regarded as duplicates and one of them was removed from the final database. The cleaning process was done using Statistica for Windows v. 13[46]. After the duplicate removal, 429,606 data were removed.

Duplicate removal was not performed for the bee database because most of the provided data lacks a unique identifier for tracking. The encoding of different specimens within the same dataset varies: in some cases, multiple rows may contain identical information for each field, while in others, all data is merged into a single row, with the number of specimens recorded. Unlike the hoverfly database, it was not possible to establish consistent association across all fields (e.g., location, coordinate, date) without the risk of removing records that were not true duplicates. Due to data wrangling and simplification made by data providers in their original datasets, an exact match between records was not achievable, preventing reliable duplicate identification. We acknowledge that this may pose a limitation; however, we have accounted for this issue throughout the data validation and cleaning process (see below). Nevertheless, this issue is limited to a few datasets and only affects certain species groups. Therefore, we consider the bee database to remain reliable.

Data Records

The final cleaned databases and the additional material used during the data collection and cleaning processes are available for download from Zenodo, a free and open-access research repository. For simplicity, two repositories have been created, and the material is organised as follows:

1. Spatio-temporal distribution of bees and hoverflies (*Zenodo*[47]). It includes:

    (i) Two occurrence databases of bees and hoverflies in "Pollinator Core" template (as presented in section 2. Data unification and compilation), saved as RDS and CSV files.

    (ii) Metadata files:

    -Metadata 1: information about the datasets for bees.
    -Metadata 2: a list of explored museums and private collections, and the references reviewed to acquire occurrence data.
    -Metadata 3: a detailed description of the fields for both databases.
    -Metadata 4: a detailed description of the calculations used in FileMakerPro to prepare and clean the hoverfly database.
    -Metadata 5: the data used to produce Figs. 4 and 5.
    -Metadata 6: the list of the dataset sources of the Estonian data (GBIF_Estonia dataset) retrieved from GBIF.

2. Taxonomic dictionaries and cleaning scripts for wild bees and hoverflies (*Zenodo*[47]). This Zenodo repository provides a zip folder for the GitHub repository implemented in Zenodo, including:

    (i) a README file with information concerning all the files and scripts provided in the repository and how to use them;

    (ii) a "scripts" folder with the scripts used to prepare, check and clean the databases;

    (iii) a "data" folder containing the files used for taxonomic cleaning for both bees and hoverflies, including the *WildBeeChecklist*, the *WildBeeDictionary*, the *HoverflyDictionary* and the *pollinatorClassification*. The *WildBeeCheklist* is the list of species names reported in Ghisbain, Rosa *et al*. 2023. The two taxonomic dictionaries contain the list of species names used for taxonomic cleaning, and include three columns: the first column contains the original names with errors (e.g., misspelling, typos, etc.), the second column lists the correct names, and the third column indicates the presence of each species in Europe based on the European checklists (for bees Ghisbain, Rosa, *et al*.[42], for hoverflies Reverté, Miličić, *et al*.[28]). The *pollinatorClassification* file is the taxonomic backbones used to associate all relative taxonomic information, such as Order, Family, Authorship, etc.

    In addition to these files, there are three additional folders:

(a) in the first folder "shapefile", we provided the shape files to associate the administrative level (country, stateProvince and county);

(b) in the second folder "working_directory", we provided an example of a dataset that can be used to run the scripts;

(c) in the third folder "ToFill", we provided a detailed description on how to collect and organise the data using the same standard template provided in this manuscript ("ToFill_FieldDescription.xlsx"), and an empty template ready to use ("ToFill_fill_Me.xlsx" or "ToFill.csv"). A README file ("ToFill_ReadMe.csv") is also provided.

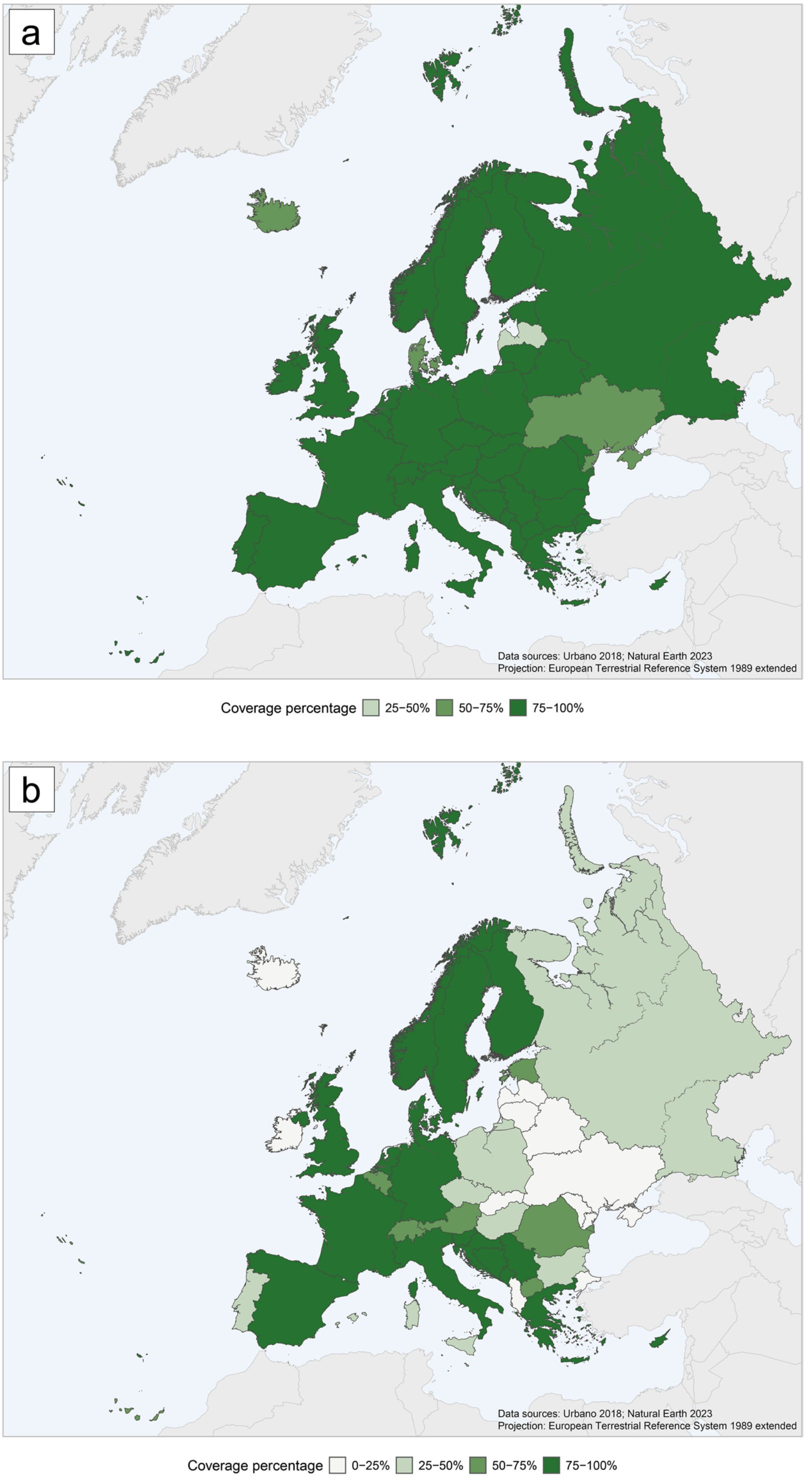

Fig. 4 Map of Europe showing the proportion of (**a**) bee and (**b**) hoverfly species covered by our database compared to the national checklists of European bees and hoverflies[28]. Colour intensity indicates the proportion of species covered by our database relative to the total number of species reported per country. The data used to produce this figure are available in metadata 5 in Sentil, *et al.*[47].

Data Overview

This work resulted in two comprehensive databases counting 4,341,684 and 1,036,181 data for bees and hoverflies, respectively. Overall, the databases covered 97% of the European bee species (2,083 species out of 2,138) and 97% of the European hoverfly European species (886 species out of 913) (see Fig. 3). The countries with the highest number of bee species in our database are Spain (1,050), Greece (1,024), Italy (907) and France (902) (Fig. 4a) and countries with the highest number of hoverfly species are France (546), Serbia (443), Germany

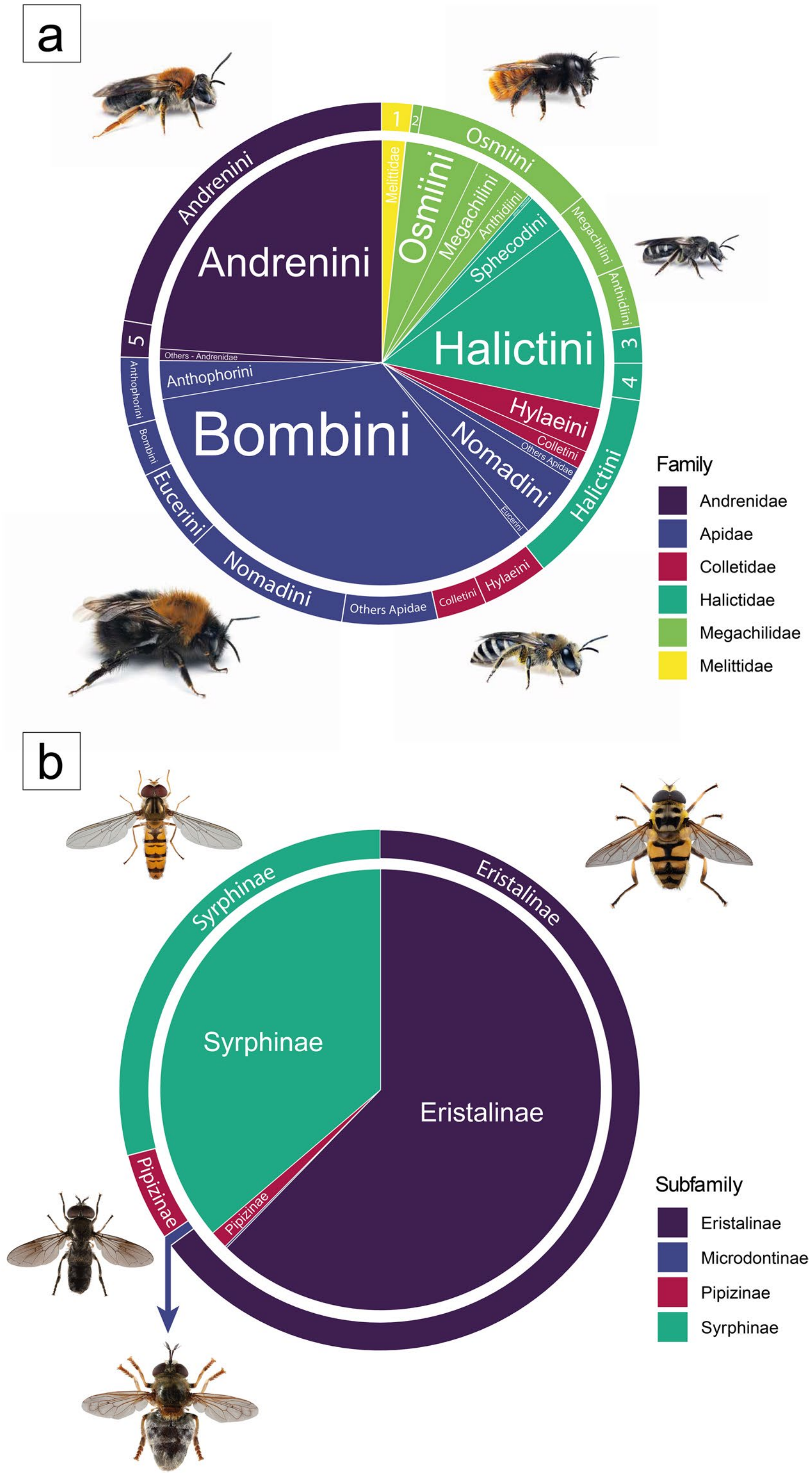

Fig. 5 Visual representation of the database taxonomic composition for (**a**) wild bees and (**b**) hoverflies. Each panel combines a donut chart and a pie chart. The donut chart illustrates the proportion of species present in Europe, while the pie chart shows the proportion of records in the database, grouped by taxonomic rank (tribes for bees, subfamilies for hoverflies). Taxonomic groups with fewer than 60,000 records per family were grouped under "Others." Numbers in the pie charts refer to the following taxonomic groups: 1 = Melittidae, 2 = Other Megachilidae, 3 = Sphecodini, 4 = Other Halictidae, 5 = Other Andrenidae. The data underlying this figure are available in Reverté, Miličić, *et al.*[28] and metadata 5 in Sentil, *et al.*[47]. Bee photographic material provided by the Beelibre team (beelibre.lu), and selected by Antonio Cruz and Fernanda Herrera-Mesías. Hoverfly photographic material provided by Sander Bot.

(426) and Italy (414) (Fig. 4b). The bee families with the highest number of records in our database (Fig. 5a) are Apidae (1,837,090), Andrenidae (1,078,322), and Halictidae (732,843), followed by Megachilidae (423,336), Colletidae (197,751), and Melittidae (72,342). The hoverfly subfamily with the highest number of records (Fig. 5b) is Eristalinae (645,502), followed by Syrphinae (375,541), Pipizinae (13,647) and Microdontinae (1,491).

Technical Validation

The validation of the spatial distribution was conducted by taxonomists and national experts. During this process, doubtful records not confirmed by experts were removed from the database.

For bees, the technical validation process followed these steps: (i) all data with spatial coordinates were split into different groups based on the Family (e.g., Halictidae) or Tribe (e.g., Anthidiini), (ii) for each species within each group a static map was made, with an associated Excel file where the information of the records was provided (e.g., taxonomic information, spatial and temporal information, etc.) and where a validation column was added for the following steps, (iii) each group has been assigned to one or more experts to review the maps and to validate or flag the incorrect points, (iv) if the distribution of the species was incomplete, new overlooked records were provided by experts and included to fill the gaps on the maps, (v) based on the validation column (filled with "OK" for valid records or "DELETE" for flagged records or "ADD" for additional records) a new version of the maps and the Excel files were made for each species, in which the incorrectly flagged points were removed. Steps from (iii) to (v) were conceived as an iterative process until all experts approved the final version of the maps. Only validated and additional records were retained and merged into a final database. At the end of this process, 775,590 records were removed and 886,684 were added (Fig. 1).

For hoverflies, technical validation was carried out by Ante Vujić for all species through visual inspection of maps created in QGIS version 3.22.4[49]. These maps included associated files with geographic coordinates, and any doubtful data points were removed. For certain species, additional experts familiar with the regions from which the questionable data originated were consulted to verify the issues. In total, 53 records were removed during this process.

Databases limitations. Despite the great effort that has been done to collect and validate the occurrence records in the bee database, it presents some limitations due to the presence of what can be termed "pseudodata" concerning the genus *Andrena*. Specifically, "pseudodata" records originate from an unpublished *Andrena* monograph of Klaus Warncke which included maps with distribution points added by hand; these maps were later published by Gusenleitner & Schwarz[50]. These distribution maps were scanned and digitally transformed in order to generate "occurrence points" on a map (forming a grid pattern easily recognisable when plotting the points), and to create machine-readable records in a "specimen" database. Therefore, these records are not directly tied to individual specimens or collection dates (all records refer to the year 1989, which is the year that this monograph was last worked on), and hence could misrepresent the true size of the dataset in terms of occurrence records. However, these records are useful for range delineation (e.g., creation of minimum convex polygons) and have been then included in the database to calculate the maximum area extent in the updated Red List of European Bees.

Pseudodata records were identified by filtering the *Andrena* records from the BDFGM dataset, which contain no collection dates other than the general publication year of 1989. Subsequently, using QGIS mapping software, records that did not align with the expected grid pattern were manually removed to avoid excluding valid data. Records that are aligned with the grid patterns have been removed. For this purpose and to help data users to easily locate these records, a new column named "isPseudodata" has been added to the bee database, with the value TRUE indicating the presence of pseudodata records.

The Syrphidae database is a compilation of data from multiple sources. While it includes most known species, there are significant disparities in coverage between different species and countries. For the rarest species, the majority of existing records have been incorporated, largely thanks to efforts related to the European Red List. In certain genera—particularly *Brachyopa* and, to a lesser extent, *Merodon*—the database captures a substantial proportion of all known records. However, for most other genera, the records are more fragmented and inconsistently represented. Similarly, geographic coverage varies. Some countries, such as Serbia, Greece, and other parts of the Balkans, are well represented in the database. Others, like the Netherlands and the United Kingdom, contain large numbers of records; however, these are predominantly recent observations of photographed flies submitted through platforms like Observation.org and iNaturalist. This results in a high number of records for large, easily identifiable species, while older records and sightings of smaller or more cryptic species are underrepresented. Meanwhile, many countries still have only a limited number of records. In France, for instance, the INPN hosts around 160,000 hoverfly records, but the absence of a centralized national database means that many datasets from institutions and private collections remain unincorporated. This lack of coordination continues to limit access to existing information. Efforts to address these gaps are ongoing. In Italy, for example, a project launched in 2020 is monitoring pollinators—bees, hoverflies, and butterflies—across all 24 National Parks. Initial results are now being published, contributing with important new data and demonstrating the value of coordinated national initiatives in improving our understanding of hoverfly distributions.

Data availability

The bee and hoverfly databases, with their associated metadata, are available at https://doi.org/10.5281/zenodo.17107215 (Zenodo repository). The taxonomic dictionaries and cleaning scripts for wild bees and hoverflies are available at https://doi.org/10.5281/zenodo.16412138 (Zenodo repository).

Code availability

The code used for the analyses in this study is available on GitHub at [https://github.com/Safeguarding-European-wild-pollinators/SafeguardEuropeanWildBee], implemented in the Zenodo repository[48]. This repository includes all scripts and documentation necessary to reproduce the results presented in this paper. The analyses conducted in this study used several R packages for data wrangling, visualisation, and spatial analysis. Key packages included: 'dplyr'[39] (v1.1.4): for data wrangling and transformation; 'sf'[40,41] (v1.0-16): for handling spatial data; 'ggplot2'[51] (v3.5.0): for data visualisation; 'lubridate'[52] (v1.9.3): for working with date-time data; and 'tidyr'[53] (v1.3.1): for tidying and reshaping data. Refer to the Github repository for a complete list of packages and their respective versions used in the analysis.

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A. Sentil, J. Acanski, J. Benrezkallah, M. Milicic and N. de Manincor provided, processed, and validated data, and wrote the manuscript. D. Michez and G. Ghisbain provided, and validated data, and wrote the manuscript. B. DeTandt, F. Carion, I. Bartomeus, J. Diaz-Calafat, J. Thulier, M. Boustani, S. Lemaire, V. Forgeois and W. Fiordaliso provided and processed data. A. Perrard, A. Ssymank, A. Vujic, A. Zmuda, B. Geslin, C. Ruiz, D. Zimmermann, J. Devalez, J. Kierat, J. Litman, J. Paukkunen, J. Straka, M. Aubert, M .Kasparek, M. Kuhlmann, P. Bogusch, P. Rasmont, R. Santerre, S. Flaminio, S. Gadoum, T. Brau, T. J. Wood, T. Petanidou, E. Budrys, E. Dufrêne, S. M. Stojnić, T. Tot and V. Radchenko provided and validated data. A. Ricarte, M. JankoviMilosavljević and W. vanSteenis provided data and wrote the manuscript. A. Andric, A. Cappellari, A. Đorđević, A. Dormal, A. Grkovic, A. Herinckx, A. Prokhorov, A. Varnava, A. Vesnic, C. Dussaix, C. Geppert, C. Siopa, C. Tourbez, D. Imre, D. Kleijn, D. Sommaggio, E. Gazzea, E. Ockermueller, F. Sgolastra, M. Garrin,G. Pennards, G. Popov, G. Stahls, H. H. Dathe, H. Gaspar, H. Heimburg, I. Steffan-Dewenter, J. Loureiro, F. J. Ortiz-Sanchez, J. Scheper, J. Smit, J. vanSteenis, K. Janssen, L. A. FedorovaZaytseva, L. B. Carstensen, L. Cantú-Salazar, L. Lenzi, L. Likov, L. Marini, M. DeGroot, M. Gibernau, M. Jacobs, M. Mei, M. Mignot, M. Selis, M. Stavrinides, P. Biella, P. Cerretti, P. Rosa, P. Sagot, P. Y. Maestracci, R. Devorsine, R. Foldesi, S. Bot, S. Castro, S. B. Lopes, S. Patiny, S. Popov, S. Potts, S. Pruner, S. Radenkovic, S. Reverte, S. Rojo, S. Veselic, S. Vray, T. Romig, U. Maritano, V. Shparyk, V. Soon, S. Cavaillès, G. Ståhls, X. Lair, T. Skendžić and Z. Nedeljkovic provided data. M. Gerard and P. Williams validated data. All authors have read, revised, and approved the final version of the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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