IMOST: a database for non-marine ostracods in the Iberian Peninsula, the Balearic Islands and Macaronesia

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ABSTRACT

Ostracods are common microcrustaceans in inland waters, widely used as (palaeo-) environmental indicators. Information on their species distribution worldwide is extremely fragmentary, and usually biased towards some regions, hampering attaining a general view of their biogeography. The Iberian Peninsula, the Balearic Islands and Macaronesia are considered biodiversity hotspots as part of the Mediterranean Region, whose non-marine ostracod fauna was reviewed in the 1990s accounting for 88 species. Most of these data were included in the NODE database (Non-marine Ostracod Distribution in Europe). Here, we present IMOST (Ibero-Balearic and Macaronesian OSTracod database), a non-marine ostracod database for the Iberian Peninsula and the Balearic and Macaronesian islands, incorporating data included in NODE plus many new records from recently published studies and new unpublished observations. Our database stores data in separated and standardised spreadsheets, one for each data source. Moreover, the database also offers updated, reviewed and accurate coordinates of the cited occurrence and taxonomic identification. According to the data compiled in IMOST, we updated the list of non-marine ostracods in the studied region from 88 to 118 species. Nevertheless, we expect that the actual number of species for the included regions should be higher, considering other Mediterranean countries with smaller areas but more extensive surveys (e.g. 152 species in Italy). The updated database is instrumental for our understanding of the biodiversity and biogeographic patterns of these organisms in this hotspot, as well as for analysing their species-environment relationships in a context of global changes.

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INTRODUCTION

Ostracods are small crustaceans (0.3-5 mm long) with a characteristic carapace formed by two calcified valves (Meisch, 2000). They are common in a wide range of aquatic environments, either marine or non-marine. All living non-marine ostracods (more than 2,000 species known to date; Meisch *et al.*, 2019) belong to the order Podocopida and they are classified into three superfamilies: Cypridoidea, Cytheroidea and Darwinuloidea (Meisch, 2000). Records of their species distribution have provided valuable information about patterns in biodiversity (Baltanás and Danielopol, 2013), species-environment relationships (Mezquita *et al.*, 2005) and evolutionary biology (Schmit *et al.*, 2013). However, to be able to carry out these studies, ostracod records should be stored in standardised, comprehensive and accessible databases with accurate coordinates (Huang *et al.*, 2022).

Particularly, the NODE database (Nonmarine Ostracod Distribution in Europe) compiled georeferenced occurrences of non-marine ostracods of Europe, North Africa, Asia Minor and the Middle East, mainly based on literature published until the end of the 20th century (Horne *et al.*, 1998). This database contains more than 10,000 occurrences of c. 400 species, Poland, Germany and France

being the countries with the most species cited, with 127, 119 and 115 species respectively. However, ostracods from other areas have been less intensively studied and they could have higher biodiversity, particularly in the Mediterranean regions. Recently, an updated Italian checklist of non-marine ostracods reached the highest country-level species richness in Europe (152 species; Pieri *et al.*, 2015). The NODE database now contributes, with other regional databases, to the OMEGA (Ostracod Metadatabase of Environmental and Geographical Attributes) project which includes records from North America, Asia and Africa (Horne *et al.*, 2011; Huang *et al.*, 2022). New data continue to be added to NODE, and a process of georeference validation combined with taxonomic harmonisation is under way in preparation for contributions to public access data repositories such as GBIF (Global Biodiversity Information Facility; www.gbif.org) and Neotoma (www.neotomadb.org).

The last published ostracod fauna of the Iberian Peninsula, the Balearic Islands and Macaronesia listed 88 species of non-marine ostracods (Meisch and Broodbakker, 1993; Baltanás *et al.*, 1996; Scharf and Meisch, 2014), a relatively low species richness considering its area and habitat diversity. However, many recent publications were not included in this account, so a higher actual number was expected. We aimed at updating this list, and at the same time providing more accurate geographic information on species distribution, reviewing those locations with vague place names and descriptions.

The Iberian Peninsula and the Balearic Islands show a unique and rich biodiversity influenced by two main geographical features (Miracle, 1982). First, the area remained outside the main ice sheets during the Pleistocene glaciations, acting as a biogeographic refuge for many species. Second, this region displays a heterogeneous topography and climatology, further contributing to higher expected species richness. In this context, a more recent review on the non-marine ostracods of mainland Portugal has listed 33 species (all of them previously found in Spain; Martins *et al.*, 2010). Nevertheless, we expect that the amount of non-marine species in the Iberian Peninsula should be similar to other central European or Mediterranean countries with similar spatial extent.

On the other hand, Macaronesia is composed of five archipelagos (the Azores, Madeira, Savage Islands, Canary Islands and Cape Verde), where we can find lots of endemisms for plants, terrestrial snails and arthropods (Florencio *et al.*, 2021). In these islands, diversity is highly influenced by a wide range of altitudes, island sizes and levels of geographic isolation from the mainland (e.g., 96 km from Fuerteventura to Africa, and almost 2,000 km from Flores to the Iberian Peninsula). Moreover, their flora and fauna also vary among islands due to contrasting climatic conditions according to a latitudinal extent of 25º (from temperate to warm arid climate, in the Azores and Cape Verde, respectively). However, the non-marine ostracods of these archipelagos have all been found in the mainland, stressing the dispersal abilities of these organisms (e.g., through bird phoresis; Meisch and Broodbakker, 1993).

Here, we present IMOST (Ibero-Balearic and Macaronesian Ostracod database), a non-marine ostracod database with georeferenced locations for the Iberian Peninsula, and the Balearic and Macaronesian Islands. Our objective is to provide updated and open data on the distribution of these organisms. We built a simple, accessible and comprehensive system to store and share the database in a set of standardised spreadsheets. These spreadsheets can be easily combined to obtain an overall database to be shared in GBIF (a leading repository of global biodiversity). Along with the database, we also provide an updated checklist of the non-marine ostracod species present in the Iberian Peninsula, the Balearic and Macaronesian islands.

METHODS

Study area

The Iberian Peninsula is located in southwestern Europe, between the Mediterranean Sea and the Atlantic Ocean. It comprises an area of c. 600,000 km², including the mainland territories of Portugal, Spain and Andorra. Broad atmospheric circulation and topography have generated a precipitation gradient from northwest to southeast (from more than 2000 mm/year to less than 200 mm/year; Capel Molina, 1978; Fick and Hijmans, 2017), which influences the landscapes in the Iberian Peninsula. Water bodies are strongly influenced by climate seasonality, with main rainy periods in autumn and spring and hot summers (especially in the southeastern part). Standing waters are mostly represented by shallow lakes, ponds and coastal wetlands, with temporary hydroperiods in many cases. Deep, permanent lakes are scarce, mostly corresponding to reservoirs, small lakes restricted to high mountain areas, and a few karstic lakes. Lotic ecosystems are dominated by (often temporary) streams and ravines, and the main rivers have been intensively regulated by dams built during the 20th century. The Balearic Islands are situated near the eastern Mediterranean coast of the Iberian Peninsula, with similar climate and aquatic environments.

On the other hand, the Macaronesian islands constitute a unique biogeographic region located in the Northeast Atlantic Ocean, but highly influenced by the Mediterranean Basin (near North Africa and South Europe; Florencio *et al.*, 2021). These archipelagos are composed of small volcanic islands which show a wide range of climatic conditions (such as temperate,

Mediterranean or arid climates), depending on latitude and prevailing winds interacting with main mountains. In these steep islands with ephemeral ravines, water resources have been crucial for human settlements. Consequently, wells and channels are common, though other unique habitats are also representative, such as volcanic lakes (Malmqvist *et al.*, 1997).

Database sources

The present database (IMOST) compiled georeferenced occurrences of non-marine ostracods in the study area from 1887 (De Guerne, 1888) to 2022. These data originate both from published records and from unpublished observations. Initially, we checked and added the occurrences previously included in NODE (Horne *et al.*, 1998) for the study area, and then further added published and unpublished records not included in NODE.

Most ostracod records in the database originated from field samples fixed in the field (e.g. with ethanol), and transported to the laboratory for inspection. Ostracod individuals are usually sorted out from these samples under a binocular microscope in the laboratory and identified using standard references (Meisch, 2000). Samples of living ostracods can be collected by pulling a plankton or hand net close to the sediment or through the vegetation (Meisch, 2000). Additionally, some studies also record empty carapaces or unarticulated valves (i.e. exuviae or dead animal remains) from surficial sediments (Martín-Rubio *et al.*, 2005; Poquet *et al.*, 2008; Castillo-Escrivà *et al.*, 2017). We include all these records in a homogeneous format, considering the ostracod community of each sample, with all the species found there (i.e. independent species occurrences were not the basic unit as in other databases, such as NODE; Horne *et al.*, 1998), although we later split each sample into its corresponding species records to allow easy database sharing in a standard structure for biodiversity data repositories, as in NODE or GBIF.

Database structure

The database is composed of a group of datasets, each one introduced in a standardised spreadsheet (Excel file; .xlsx). We introduced each dataset in a different file, which facilitates adding or editing data without handling the whole database. Excel files are a suitable way to store data in a set of tables with different information (Broman and Woo, 2018). In our case, each spreadsheet file incorporated five sheets: *sample*, *community*, *environment*, *taxonomy* and *summary* (Tab. 1).

Tab. 1. Contents of the four sheets composing the spreadsheets in the IMOST database.

Sheet	Column name	Description
sample	eventID	sample code (source code and sample number; source_001)
	collectionCode	source code
	basisOfRecord	specific nature of the data record (fossil specimen or living specimen)
	modified	date of the last modification in the database (yyyy-mm-dd)
	eventDate	sampling date (yyyy-mm-dd)
	decimalLatitude	geographic latitude
	decimalLongitude	geographic longitude
	geodeticDatum	datum of latitude and longitude (WGS 84)
	georeferenceVerificationStatus	coordinate accuracy (exact, close, municipality, region)
	locality	popular site name
	habitat	habitat type (stream, pond, spring...)
	countryCode	ISO 3166-1-alpha-2 country codes (e.g., PT = Portugal)
	node	Is the record in the NODE database? Yes or No
	bibliographicCitation	Publication reference or Unpublished
	organismQuantityType	type of measure (presence, abundance, biomass)
community	Species records for each sample, with eventID as the first column; the same names published	
environment	Environmental variables (if there are); at least the first column is eventID	
taxonomy	speciesID	species code used in *community* (e.g., *Cypris_bispinosa*)
	speciesIDRev	species code reviewed, considering recent taxonomic advances
	Taxonomic ranks in different columns; kingdom, phylum, class, order, family, genus, specificEpithet and infraspecificEpithet	
	scientificName	reviewed scientific name; e.g. *Sarscypridopsis aculeata* (Costa, 1847)
	verbatimIdentification	scientific name in the publication; *Cypridopsis aculeata* Costa, 1847
	taxonRank	identification accuracy (Family, Genus, Species)

In the *sample* sheet, we introduced the coordinates and the sampling date for each sample in the dataset, in addition to a unique sample code. We used WGS84 projection for all coordinates, reprojecting when it was necessary and verifying the location in Google Earth (https://earth.google.com). As not all the sources provide exact locations, we added a column with the accuracy of the sampling locations (e.g. *Exact* for accurate locations; *Close* when we did not find an exact location but provided coordinates which should be closer than 10 km to the exact sampling point; *Municipality* when we only got the coordinates of a village, whereas exact locations should be in its surroundings; *Region* when we only got the name of wide territories or islands). When ostracod remains (shells and valves) were also identified, we split the sample in two rows indicating the basis of the record: living or fossil (i.e. shell remains, either recent or older) specimens. Furthermore, the *sample* table also includes other relevant features, such as the publication source (if any), a code name for the source, site name, country code, type of habitat and type of species counts (e.g., presence or abundance).

With the same rows as the sample table, the *community* sheet contains the species records, with samples in rows and species in columns. These rows are the same for the *environment* sheet, which incorporates the environmental variables associated with each sample (e.g., temperature, water electrical conductivity, pH), if available. On the other hand, the *taxonomy* sheet has all the taxonomic information for each species (in rows). Species names were preserved in the dataset as they appeared in the publications, independently of recent taxonomic changes, known misidentifications or writing mistakes, but we also added revised or accepted names (according to Meisch *et al.*, 2019) in other columns, facilitating taxonomic harmonisation with other databases. Finally, the *summary* sheet includes the metadata of each source (e.g., authors, publication title and journal, year) and an explanation of the other sheets (e.g., list of column variables and their meaning, environmental variable units).

Eventually, all the datasets can be combined in a full spreadsheet in two formats: wide and long. In the wide format, each row corresponds to one sample and columns are species, sample information and environmental variables (i.e., each row contains all the data for one sample). The wide format is recommended for analysing data in community ecology (e.g. multivariate analyses, biodiversity indices; Oksanen *et al.*, 2020). On the other hand, the long format displays each species occurrence in separated rows, where one sample could be extended in various rows (as many rows as the number of species in that sample). This is the format generally used in biodiversity repositories (e.g., GBIF) and it is appropriate for the study of species distributions in biogeography (for example, species distribution models; Naimi and Araújo, 2016). These two full spreadsheets, the database path and the R scripts (R Core Team, 2022) used for assembling and managing the database are publicly accessible at https://github.com/andreucastillo/imost. The database in long format is available in GBIF (DOI: https://doi.org/10.15470/wxb6hm; https://www.gbif.org/dataset/e17b874d-94c7-4eb3-807b-1efedac8e3ba; Castillo-Escrivà *et al*., 2023).

RESULTS

The present database (IMOST) consists of 112 datasets of ostracods from the Iberian Peninsula, Balearic Islands and Macaronesia, accounting for 3344 samples altogether (Fig. 1A; Supplementary Tab. S1). Most records had exact coordinates for the sampling locations (2742 samples). However, some studies from Macaronesia only provided the name of the island or vague descriptions, resulting in 102 out of 360 samples of these archipelagos located in central points of the corresponding islands. The sampled area encompasses almost all the Iberian Peninsula and the Balearic and Macaronesian islands, but a high number of samples were concentrated in specific regions of the East (e.g., surrounding Valencia), South and Central part of the Iberian Peninsula. Most of the samples were collected during the last 30 years (i.e., since 1990; Fig. 1B), although Margalef's earlier contributions are remarkable in the 1940s and 1950s (257 samples). Generally, samples included living specimens (2888 samples), whereas ostracod remains were identified only in 456 samples. In a long format, these samples result in 7548 species occurrences, corresponding to 6393 occurrences of individuals collected alive and 1155 occurrences of dead ostracod remains.

The database contains the records of 118 non-marine ostracod species hitherto, belonging to 47 genera and 12 families (Supplementary Tab. S2). We also included in the database records of 15 marine species, which appear together with non-marine ostracods in coastal wetlands or estuaries. However, we excluded these marine species in the present checklist of non-marine ostracods. On the other hand, 6 out of 118 non-marine ostracods were exclusively recorded as shell remains. We also added to the database two ostracod species of the family Entocytheridae (symbionts of other crustaceans like crayfish), although Mestre *et al*. (2014) provided a detailed global database of this family. In this list of 118 species, we only considered those ostracods identified at least to species rank (7143 records), but there are also records of ostracods that have not been assigned to a particular species in a genus, either because the species was not known for some adults or they were juveniles that could not be identified to species level (examples include *Sarscypridopsis* sp. or *Heterocypris* sp. with 104 and 39 occurrences, respectively).

The superfamily Cypridoidea was the most common in the database, Cyprididae being the family with more species and occurrences (63 species; 4822 occurrences), followed by Candonidae (28 species; 1077 occurrences) and Ilyocyprididae (9 species; 734 occurrences; Fig. 2). In particular, 26 out of 118 species have contributed to more than 100 occurrences (22 species of the Cypridoidea superfamily). Among them, *Eucypris virens* (477 occurrences) and *Heterocypris incongruens* (451 occurrences) were the species with more occurrences. *Cyprideis torosa* (220 occurrences) and *Darwinula stevensoni* (130 occurrences) were the most represented species of the superfamilies Cytheroidea and Darwinuloidea, respectively.

Almost all the species occurred in the Iberian Peninsula (115 out of 118 species). In the Balearic Islands, we found 38 species, one of which was exclusively found in these islands considering the studied area (*Mixtacandona* cf. *botosaneanui*). In Macaronesia, 30 species were collected, most of them in the Canary Islands (27 species). However, we did not find any record of the superfamily Darwinuloidea in Macaronesia. Moreover, two species were restricted to the Azores and Cape Verde in the studied area (*Pseudocandona stagnalis* and *Heterocypris symmetrica*, respectively). On the other hand, *Cypridopsis lusatica* and *Bradleycypris obliqua* appeared in the Iberian Peninsula and also in all the archipelagos studied (except Cape Verde).

DISCUSSION

With the IMOST database, we updated the lists of non-marine ostracods in the Iberian Peninsula, Balearic and Macaronesian Islands from 88 (Meisch and Broodbakker, 1993; Baltanás *et al.*, 1996; Scharf and Meisch, 2014) to 118 species. The database added 6138 new records to those provided in the NODE database and also increased the number of georeferenced occurrences in GBIF for this

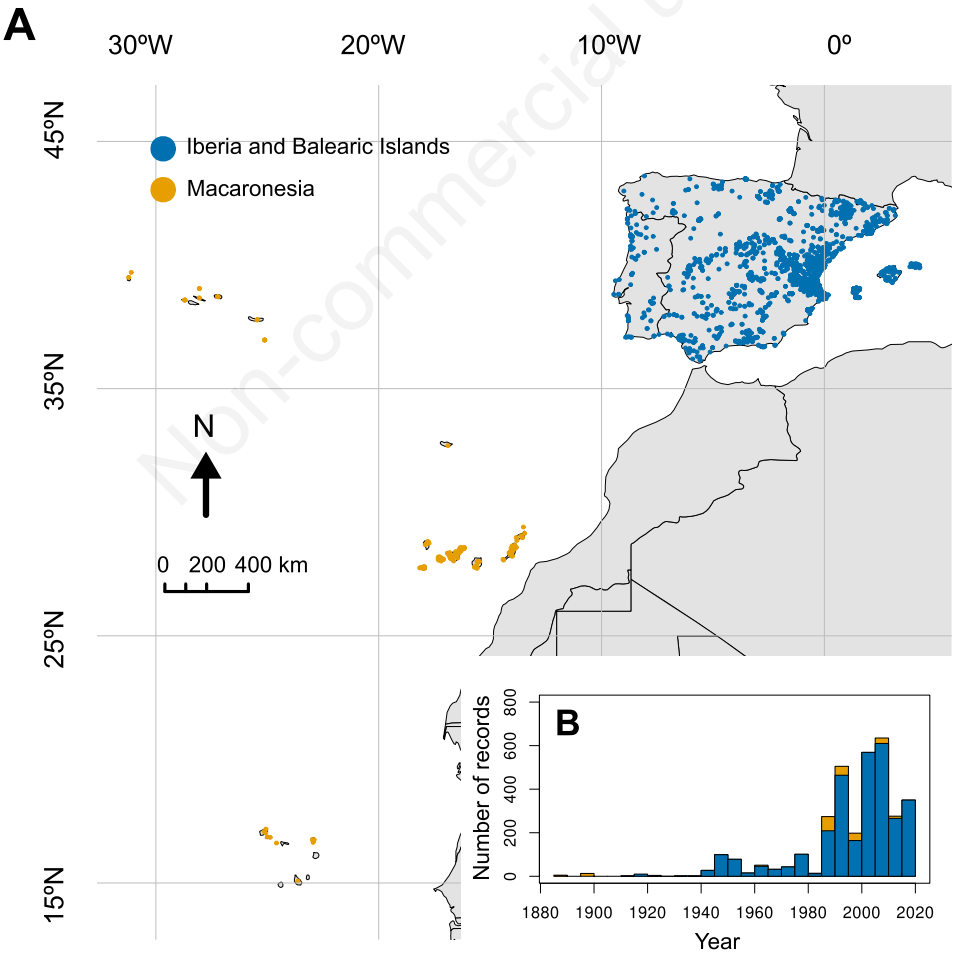

Fig. 1. Spatial distribution of ostracod records included in the IMOST database (A) in the Iberian Peninsula and the Balearic Islands (blue) and Macaronesia (orange), and the number of records through time since 1887 (B).

region, which were only represented by 33 species with 222 records with coordinates. However, the present richness of non-marine ostracods in the Iberian Peninsula might still be higher, compared with other European countries (especially taking into account Italy with 152 species in a smaller area; Pieri *et al.*, 2015).

Some species previously listed in the Iberian Peninsula (Baltanás *et al.*, 1996) were excluded from the present checklist, as they were reassigned to other species. We considered that the records of *Cypridopsis parva* in the Iberian Peninsula belong to *Cypridopsis concolor*, according to a detailed work on integrative taxonomy (Costa, 2021), also allowing to differentiate it from *Cypridopsis vidua*, which was considered a senior synonym of this species (Meisch *et al.*, 2019). Furthermore, Margalef's records of *Herpetocypris reptans* were here transferred into *Herpetocypris* sp., as the taxonomy of the genus *Herpetocypris* was not clearly established before the review of González-Mozo *et al*. (1996), and *H. reptans* never appeared in subsequent studies in the area. In addition, all *Fabaeformiscandona holzkampfi* occurrences in the area were transferred to *Fabaeformiscandona subacuta*, according to Escrivà *et al*. (2012). Finally, Margalef's citations of *Notodromas monacha* in the Iberian Peninsula were reassigned to *Notodromas persica*, according to the size and posterodorsal shell morphology (higher in *N. monacha*) shown in the drawings by Margalef (1946a). All these changes suggest that *Cypridopsis parva* (a doubtful synonym of *Cypridopsis vidua*; Meisch *et al.*, 2019), *Herpetocypris reptans*, *Fabaeformiscandona holzkampfi* and *Notodromas monacha* may be rare or absent in the Iberian Peninsula, whereas they should be more common in central and northern Europe (although they were also found in other Mediterranean regions, such as Central Italy, Sardinia or Sicily; Pieri *et al.*, 2015, 2020). Additionally, we transferred the citations of *Candona*

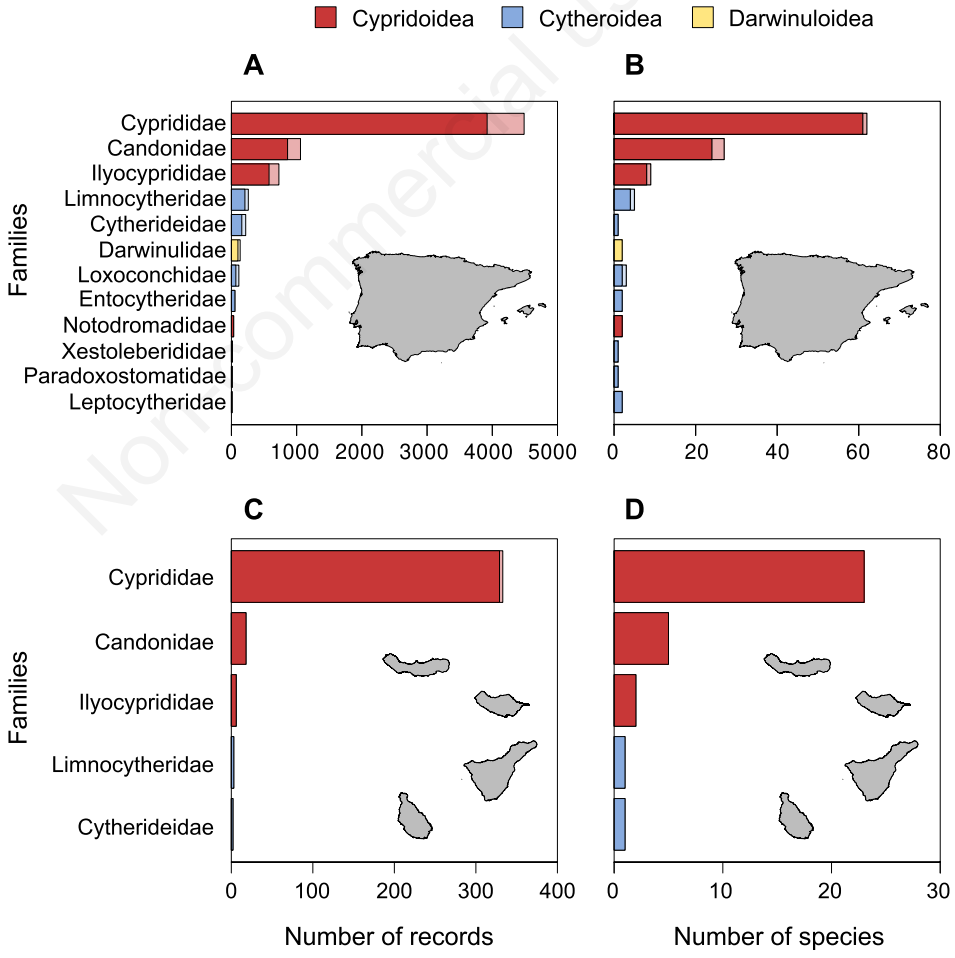

Fig. 2. Number of records and number of non-marine ostracod species in each family in the Iberian Peninsula and the Balearic Islands (A,B) and Macaronesia (C,D) in the IMOST database. The three superfamilies of non-marine ostracods are represented by different colours. Regular colours mean ostracods retrieved alive, whereas light colours correspond to records of ostracod remains.

vasconica (Margalef, 1946b) and *Candona bertrandi* (Margalef, 1958) to *Neglecandona neglecta*, following Meisch *et al*. (2019).

We suggest that future efforts should focus on three principal fronts for reaching a better knowledge of the ostracod species richness and distribution in the studied area. First, some regions of the area have been historically neglected, mainly those located in the north and west of the Iberian Peninsula, and the archipelagos of the Azores, Madeira and Cape Verde. Additionally, many of the previous records in the Iberian Peninsula and Macaronesia were obtained prior to the 1990s (Margalef, 1955; Paulo and Moutinho, 1983; Meisch and Broodbakker, 1993). The northwestern part of the northwestern Iberian Peninsula has some particularities regarding climatic conditions compared with the central and southeastern part, due to a higher influence of the Atlantic Ocean. We suggest that a wider sampling program in these regions may help fill this biogeographic gap, likely allowing us to find new records for species with a typical distribution in Central and Northern Europe that remain unknown to the Iberian Peninsula.

Second, the database includes several species with provisional or unresolved identifications, which should be checked in the future. For example, Mezquita *et al*. (1999) cited a *Sarscypridopsis* cf. *aculeata* without spines and similar in shape to fossil specimens found by Fuhrmann and Goth (2011) in Madeira, which posteriorly was found in more sites and identified as *Sarscypridopsis* sp. (Mezquita *et al.*, 2001; Escrivà *et al.*, 2015; Castillo-Escrivà *et al.*, 2017). An integration of morphological, genetic and ecological approaches might be convenient to describe this species and formally name it, taking into account that cryptic species are common in these crustaceans (Koenders *et al.*, 2012). Another example is *Ilyocypris biplicata* var. *anomala*, a variety described by Gauthier (1938) from northern Africa, and which we consider is actually a different species from *I. biplicata* and from its senior synonym *I. gibba*, and which deserves further investigation.

Third, some of the new species in the list are exotic species, particularly associated with rice fields (*Hemicypris barbadensis*, *Candonocypris novaezelandiae* and *Fabaeformiscandona subacuta*; Valls *et al.*, 2014). These ecosystems seem a suitable habitat for the spreading of exotic species, by means of bird dispersal and human activities. Many rice fields are generally located in the main wetlands of the Mediterranean coasts, which function as stepping stones in the migration routes of numerous birds. Indeed, waterbirds can be important dispersers of exotic ostracods (or their eggs; Valls *et al.*, 2017), linking all the wetlands visited in their routes, and humans can also disperse organisms between wetlands (Valls *et al.*, 2016). Once in the rice field, artificial inundation in summer offers a chance for (sub-) tropical species to colonise warm temporary waters, which are unusual in the Mediterranean, because of its dry summers. Consequently, monitoring rice fields might be critical to detect the arrival of exotic species into Iberian wetlands.

The present IMOST database is just the beginning of a long-term compilation of data of non-marine ostracods in the Iberian Peninsula, Balearic and Macaronesian islands. New records and publications will be incorporated in the future, and consequently ostracod distributions will be more complete in GBIF when its IMOST datasets are replaced with updated versions. To facilitate the effective contribution of IMOST to the wider (Holarctic or even global) mapping and analysis of species' distributions, the specific names and generic assignments that are considered to be valid must be harmonised with those of other databases, taking account of synonyms and misidentifications, with the aim of achieving agreed, consistent taxonomic nomenclature (Horne *et al.*, 2012). Species distributions are one of the main issues in biogeography and ecology, with a growing relevance in the current development of species distribution models in a context of global warming. Some bioclimatic envelope modelling studies have shown how southern macroinvertebrate species may move northwards in response to present and future climate change, replacing northern species as northern regions become warmer (Domisch *et al*., 2013). Large distributional databases such as NODE and IMOST have enormous potential to facilitate similar modelling of ostracod species' present and future distributions both geographically and climatically. The ostracod communities in these studied regions could also present altitudinal dispersal processes (Poquet and Mesquita-Joanes, 2011), and some inland water bodies may disappear due to either lack of water or sea flooding (Estrela-Segrelles *et al.*, 2021). Comprehensive and available databases will help us to predict changes in species distributions for managing and preserving biodiversity.

CONCLUSIONS

IMOST is a database of non-marine ostracods from the Iberian Peninsula, Balearic and Macaronesian islands, containing 3344 georeferenced samples and 7548 species occurrences. Based on the data compiled in IMOST, up to 118 species of non-marine ostracods are found in these regions. However, the species pool may increase in the future, by extending efforts towards less sampled regions (e.g., Northern and Western Iberian Peninsula, and the archipelagos of the Azores, Madeira and Cape Verde), reviewing uncertain species locations and monitoring the arrival of exotic species. IMOST will be updated with future studies, becoming an open database (included in GBIF) suitable for further biodiversity and species distribution analyses.

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