Diversity and Distributions

WILEY

Diversity and Distributions

RESEARCH ARTICLE OPEN ACCESS

Over 1200 Non-Native Species Are Established in the Iberian Peninsula

Ismael Soto[1] | Francisco J. Oficialdegui[1,2] | Sergio Bedmar[2] | César Capinha[3] | Ronaldo Sousa[4] | Emili García-Berthou[5] | Carolina Mendes Muniz[5] | Javier Oscoz[6] | Carlos Cano-Barbacil[7,8] | Pedro M. Anastácio[9] | Elena Angulo[2] | Christian Arnanz[10,11] | Margarita Florencio[12] | Antonín Kouba[1] | Rafael Miranda[6] | Francisco J. Oliva-Paterna[13] | Filipe Ribeiro[14] | Jordi López-Pujol[15,16] | Meritxell Dalmau[17] | Clara Pladevall[17] | Miguel Porto[18,19,20,21] | Phillip J. Haubrock[1,22,23] | Elizabeta Briski[24]

[1]Faculty of Fisheries and Protection of Waters, South Bohemian Research Centre of Aquaculture and Biodiversity of Hydrocenoses, University of South Bohemia in České Budějovice, České Budějovice, Czech Republic | [2]Department of Conservation Biology and Global Change, Doñana Biological Station (CSIC), Seville, Spain | [3]Centre of Geographical Studies, Institute of Geography and Spatial Planning, University of Lisbon, Lisbon, Portugal & Associate Laboratory Terra, Lisbon, Portugal | [4]CBMA—Centre for Molecular and Environmental Biology/ARNET-Aquatic Research Network/IB-S, Institute of Science and Innovation for Bio-Sustainability, Department of Biology, University of Minho, Campus Gualtar, Braga, Portugal | [5]GRECO, Institute of Aquatic Ecology, University of Girona, Girona, Catalonia, Spain | [6]Instituto de Biodiversidad y Medioambiente (BIOMA), University of Navarra, Pamplona, Spain | [7]Department of River Ecology and Conservation, Senckenberg Research Institute and Natural History Museum Frankfurt, Gelnhausen, Germany | [8]Departamento de Biodiversidad y Biología Evolutiva, Museo Nacional de Ciencias Naturales, CSIC, Madrid, Spain | [9]MARE–Marine and Environmental Sciences Centre, ARNET–Aquatic Research Network, Institute for Research and Advanced Training (IIFA), University of Évora, Évora, Portugal | [10]Inland-Water Ecosystems Team (I-WET), Departamento de Ecología, Universidad Autónoma de Madrid, Madrid, Spain | [11]Centro de Investigación en Biodiversidad y Cambio Global, Universidad Autónoma de Madrid, Madrid, Spain | [12]Department of Ecology and Evolution, Doñana Biological Station (CSIC), Seville, Spain | [13]Departamento de Zoología y Antropología Física, Universidad de Murcia, Murcia, Spain | [14]MARE–Marine and Environmental Sciences Centre, ARNET - Aquatic Research Network, Faculdade de Ciências da Universidade de Lisboa, Lisboa, Portugal | [15]Botanic Institute of Barcelona (IBB), CSIC-CMCNB, Barcelona, Spain | [16]Escuela de Ciencias Ambientales, Universidad Espíritu Santo (UEES), Ecuador | [17]Andorra Recerca + Innovació (AR+I), Sant Julià de Lòria, Andorra | [18]CIBIO, Centro de Investigação Em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Campus de Vairão, Universidade do Porto, Vairão, Portugal | [19]CIBIO, Centro de Investigação Em Biodiversidade e Recursos Genéticos, InBIO Laboratório Associado, Instituto Superior de Agronomia, Universidade de Lisboa, Lisboa, Portugal | [20]BIOPOLIS Program in Genomics, Biodiversity and Land Planning, CIBIO, Campus de Vairão, Vairão, Portugal | [21]EBM, Estação Biológica de Mértola, Portugal | [22]Department of Life and Environmental Sciences, Faculty of Science and Technology, Bournemouth University, Dorset, UK | [23]Center for Applied Mathematics and Bioinformatics, Department of Mathematics and Natural Sciences, Gulf University for Science and Technology, Hawally, Kuwait | [24]GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, Kiel, Germany

Correspondence: Ismael Soto (isma-sa@hotmail.com) | Elizabeta Briski (ebriski@geomar.de)

Received: 31 March 2025 | **Revised:** 6 August 2025 | **Accepted:** 8 August 2025

Editor: Yunwei Dong

Funding: This work was supported by FCT through InvaSTOP research grant (https://doi.org/10.54499/2023.12533.PEX), 10.54499/2023.12533.PEX. MULTI-CRASH: Multi-dimensional ecological cascades triggered by an invasive species in pristine habitats (PTDC/CTA-AMB/0510/2021), PTDC/CTA-AMB/0510/2021. MEGAPREDATOR: A giant on the water: from predation pressure to population control of the European catfish (Silurus glanis) (https://doi.org/10.54499/PTDC/ASP-PES/4181/2021), 10.54499/PTDC/ASP-PES/4181/2021. TED2021-129889B-I00, TED2021-129889B-I00. PID2023-146173NB-C21, PID2023-146173NB-C21. RED2022-134338-T, RED2022-134338-T. CRAYMAP (Crayfish invasions across time and space, a multidisciplinary approach, PID2020-20026RB-I00). MCIN/AEI/10.13039/501100011033 (PID2020-119163GB-I00).

Keywords: biological invasion | first-record | invasion pathways | invasive species | spatio-temporal analysis | taxonomic diversity

ABSTRACT

Aim: As a consequence of globalisation, biological invasions have become an increasing concern due to multifaceted ecological and socio-economic impacts on biodiversity and ecosystem services. Despite the increasing availability and accessibility of data, a comprehensive assessment of established non-native species and their distribution in the Iberian Peninsula has not been conducted so far.

Location: Iberian Peninsula, including Spain, Portugal, Andorra, and Gibraltar.

Methods: We compiled a harmonised dataset of 1273 established non-native species from multiple regional, national, and global sources. We analysed taxonomic composition, introduction pathways, and native biogeographic realms. Temporal patterns were assessed using first-record data, while spatial patterns were mapped using high-resolution occurrence data from GBIF and national databases.

Results: The majority of established non-native species are vascular plants and insects, specifically of the classes Magnoliopsida and Insecta and the families Asteraceae and Formicidae, respectively. Overall, the most common pathways of introduction were escapes from human facilities and transport-related mechanisms (contaminant and stowaway), but their importance varies among countries. Established non-native species were mostly native to the other regions within the Palearctic, followed by the Nearctic and Neotropical realms. Regarding the time of introduction, first records increased steadily until the last decades of the 20th century, when the introduction rate slowed down; yet new introductions persist. Finally, our spatial analysis identified that areas with high human population density and coastal zones recorded the highest number of established non-native species.

Main Conclusion: The Iberian Peninsula hosts a high number and diversity of established non-native species. Given the ongoing rise in cumulative introductions and the role of unintentional human-driven pathways, strengthening prevention measures is vital to reduce future invasions. However, with many non-native species already established, effective management efforts are equally crucial to curb further spread and mitigate consequent impacts, especially in areas of conservation interest.

1 | Introduction

In today's globalised world, natural barriers, such as oceans, rivers, or mountains that once kept species distributions isolated, are no longer insurmountable. Human activities, including global trade and tourism, have successfully eroded these barriers, facilitating unprecedented rates of species introductions (Capinha et al. 2015; Seebens et al. 2017) to the extent that biological invasions are considered a main component of global change (Ricciardi 2007). The human-mediated invasion process involves a series of sequential stages—regardless of whether they are intentional or accidental—consisting of transport, introduction, establishment, and later on, possible spread, that individuals and populations must transit, overcoming different constraints (e.g., survival or reproduction) (Blackburn et al. 2011; Simberloff 2013). Currently, over 37,000 established non-native species have been recorded globally (IPBES 2023). A subset of them, those that have established and spread with negative impacts on the novel area (e.g., biodiversity, local ecosystems and species), are termed 'invasive' (IPBES 2023; Soto, Balzani, Carneiro, et al. 2024).

Biological invasions have become a growing concern due to their multifaceted impacts (IPBES 2023). For instance, they are among the main threats to biodiversity (Bellard et al. 2016), contributing to 60% of extinctions globally (Clavero and García-Berthou 2005). Beyond biodiversity loss, non-native species can disrupt entire ecosystems by triggering cascading effects, altering trophic webs, and changing ecosystem functioning (Ehrenfeld 2010; Vilà et al. 2010; Gutiérrez et al. 2014; Gallardo et al. 2016). These disruptions are often accompanied by monetary losses exceeding a conservative estimate of trillions of US dollars globally and an annual cost estimate of 423 billion (Diagne et al. 2021; Soto et al. 2025). Moreover, the impacts of non-native species are expected to intensify through synergistic interactions with other anthropogenic drivers, such as climate change, pollution, and changes in land and sea use (Bellard et al. 2016). Worryingly, it has been argued that there is no sign of saturation in the number of new introductions at the global scale as new pools of potential invaders continue to emerge (Seebens et al. 2017; but see Haubrock et al. 2023), with approximately 200 new non-native species recorded annually (IPBES 2023).

The Iberian Peninsula is an enclave situated at the crossroads of Europe and Africa and between the Atlantic Ocean and the Mediterranean Sea, including mainland territories of Spain and Portugal, Andorra, and the British overseas territory of Gibraltar, as well as a small area of southern France (of just about 500 km^2). Its isolation by the Pyrenees and the occurrence of multiple Neogene refugia (Gómez and Lunt 2007) have led to the development of unique ecosystems, with high levels of endemism and one of the greatest biological diversities in Europe (Von 2000; Baquero and Tellería 2001; Miguel et al. 2007; Aedo et al. 2017). However, this ecological distinctiveness has also made Iberian ecosystems particularly vulnerable to biological invasions, rendering them among the most heavily invaded areas globally (Ascensão et al. 2021). Indeed, the Iberian Peninsula is one of the six global hotspots for fish invasions (Leprieur et al. 2009), with seven out of ten major basins having more non-native than native fish species (Clavero and García-Berthou 2006; Ribeiro et al. 2009). However, introduction rates have changed over time, with the first noticeable increase during the expansion of Spanish and Portuguese colonialism in the 15th and 16th centuries (Crosby Jr. 2003). Following the arrival of Christopher Columbus in America, a massive exchange of fauna and flora between the 'Old' and the 'New World' began (Crosby Jr. 2003). At the same time, other species were also imported from other regions of Europe, Africa, and Asia as the novel fauna and flora symbolised the rulers' power and control over exotic collections and menageries (Perez De Tudela and Gschwend 2007). By contrast, Gibraltar and Andorra exhibit distinct contexts for species introductions due to their non-European Union status and unique political, economic, and geographical characteristics (Sérgio et al. 2007; Aedo et al. 2013; Dawson et al. 2023). For instance, Andorra's small land area and high-altitude ecosystems, as well as Gibraltar's role as a maritime hub, contribute uniquely to their respective invasion dynamics.

Despite the increasing availability of data in recent decades and the construction of regional, national, and international databases for biological invasions like the *Global Register of Introduced and Invasive Species* (GRIIS, Pagad et al. 2018), a comprehensive taxonomic and spatio-temporal evaluation of established non-native species in the Iberian Peninsula is still lacking. Moreover, although multiple compilations of non-native species have been gathered for the Iberian Peninsula, they are restricted to specific areas or taxonomic groups (e.g., tetrapod species, Ascensão et al. 2021; inland aquatic species, Muñoz-Mas and García-Berthou 2020; Oliva-Paterna et al. 2020; freshwater fauna in Portugal, Anastácio et al. 2019; invasive species of the region of Valencia, Angulo et al. 2021; or invasive plants in Portugal, Marchante et al. 2014; Fernandes et al. 2025). Therefore, an assessment of the complete area of the Iberian Peninsula is crucial for increasing the capacity for early detection and rapid response (Lázaro-Lobo et al. 2024). This includes improving current national legally binding lists (i.e., species for which introduction is prohibited, requiring trade bans, management, and eradication efforts; Cerri et al. 2022), as developed by authorities in Spain, Portugal, or Andorra, namely the Ministry for the Ecological Transition and the Demographic Challenge (Spain), the Institute for Nature Conservation and Forests (Portugal), and the Ministry of Environment, Agriculture and Livestock (Andorra). From a management perspective, identifying invasion hotspots, i.e., areas that usually receive a high number of non-native species, is critical for controlling current invasions and preventing secondary ones (Acevedo-Limón et al. 2020; Capinha et al. 2023). At the same time, identifying areas not yet invaded, where early detection programmes should be prioritised, would mitigate the potential of future invasions (Gassó et al. 2012).

To conduct the most comprehensive analyses of non-native species in the political entities that comprise the Iberian Peninsula, we compiled a dataset of the established non-native species and determined their taxonomic status, pathways of introductions, and native biogeographic realms. Then, we conducted a temporal analysis of the first records of these species and provided a high-resolution map of their distribution ranges. Ultimately, this work aims to promote collaborative efforts among countries to avoid new non-native species introductions and mitigate the impacts of those already established in Iberia's unique ecosystems.

2 | Methods

2.1 | Data Compilation

We used a recently published European dataset of established non-native species (Henry et al. 2023)—i.e., those that have established self-sustaining populations in the wild—and then filtered it to include only species with records in the Iberian Peninsula (Spain, Portugal, Andorra, and Gibraltar). The small Iberian area of southern France (the French Cerdagne) was excluded from our dataset due to the lack of detailed information. The preliminary list was then completed using national (e.g., miteco.gob.es and icnf.pt) and regional lists (e.g., juntaex.es), national assessments of established non-native species (e.g., Ruzafa 2011; Zamora-Marín, Herrero-Reyes et al. 2023; see Table S1), and specialised web pages (e.g., ibermis.org and eei.sibic.org). The authors subsequently reviewed this list and made eventual adjustments by adding or removing species based on taxonomic expertise and/or their establishment status. We removed all records categorised as 'casual', 'absent', 'uncertain', or 'cryptogenic' and only retained established non-native species. Each scientific name was verified using the *Global Biodiversity Information Facility* backbone taxonomy (GBIF 2023) accessed through the rgbif R package (Chamberlain et al. 2017). If a species name was not found, we conducted general internet searches to verify its accuracy. Any misspellings were then corrected, and duplicate entries were removed from the dataset. Each species was then assigned to Phylum, Class, and Family and grouped into major taxonomic groups: algae, amphibians, birds, bryophytes, bryozoa, crustaceans, fishes, fungi, insects, mammals, microorganisms, molluscs, 'other invertebrates' (e.g., myriapods, diplopods, arthropods *pro parte*), reptiles, spiders, and vascular plants. This was done by matching species names with freely available open-access databases (e.g., the *Global Alien Species First Records Database*, Seebens et al. 2017).

2.2 | Pathways of Introduction

The pathways of introduction (i.e., the means through which non-native species are transported and introduced, but see Ruiz and Carlton 2003) were extracted from multiple sources. We prioritised the identification of specific pathways for each political entity through targeted literature (e.g., Ruzafa 2011; Oficialdegui et al. 2023; Zamora-Marín et al. 2023; Zamora-Marín, Herrero-Reyes et al. 2023). In cases where information was lacking, we extracted the pathways of introduction from global databases: *Global Invasive and Alien Traits and Records* (GIATAR) (Saffer et al. 2024) and the *Global Alien Species First Record Database* (Seebens et al. 2021). We followed the pathway classification provided by the *Convention on Biological Diversity* (CBD 2014), and included the following categories: (i) 'release', the intentional introduction of species into the wild, such as game species or biocontrol agents; (ii) 'escape', accidental release of species from captivity or cultivation; (iii) 'contaminant', unintentional transport of non-native organisms, including parasites or pathogens associated with transported goods; (iv) 'stowaway', non-native species associated with human transport but not to specific commodities; (v) 'corridors', unintentional introduction of non-native species via human-made infrastructures that connect previously unconnected regions; and (vi) 'unaided', secondary natural dispersal of non-native species across barriers without direct human assistance (CBD 2014). While the secondary dispersal is sometimes 'unaided', it is only possible through prior human intervention. In cases of multiple pathways identified for the same species, equal weight was assigned to each pathway (i.e., the taxon was attributed equally to each pathway).

2.3 | Native Origin of Iberian Invasions

The native range of each species was identified using web-scraping on online sources, such as *Encyclopedia of Life* (eol.org), *Plants of the World Online* (powo.science.kew.org), FishBase (fishbase.se), GISD, and GBIF (see Table S2 for all consulted databases). Each established non-native species was then assigned to one or more of the eight major biogeographic realms of the Earth (Nearctic, Neotropical, Palearctic, Afrotropical, Indo-Malayan, Australasian, Oceanian, and Antarctic), following globally recognised bioregionalisation patterns (Olson et al. 2001). The Oceanian and Australasian realms were combined due to similarities in their species composition. For species naturally distributed within two biogeographic realms, equal weight was assigned to each realm. Species with unclear native ranges or native to more than two biogeographic realms were not considered in this analysis.

2.4 | Temporal Trends of Established Non-Native Species First Records

To understand the temporal trends of first records of non-native species i.e., the earliest report of a species in each political entity, we used two approaches: (i) temporal trends of first records and (ii) accumulation of first records of non-native species over time. Data on the first records were extracted from GIATAR (see Saffer et al. 2024), the most comprehensive database of first records, which gathers over 800,000 first records globally at the country level. This database includes data from five online sources: the EPPO-GD Distribution and Reporting pages, CABI, SInAS (Seebens et al. 2020), *Inventory of Alien Invasive Species in Europe* (DAISIE), and the GBIF Occurrence API, combined with specific literature (Saffer et al. 2024). We excluded the first records classified as 'Not dated' as we considered these to be uncertain.

2.5 | Spatial Distribution of Non-Native Species

To identify the spatial distribution of non-native species and invasion hotspots, we extracted GBIF occurrences of each established non-native species identified within each political entity (GBIF 2025a, 2025b, 2025c) using the *occ_download* function from the rgbif R package (Chamberlain et al. 2017). We cleaned the data to ensure that the occurrences aligned with the boundaries of the respective territories and removed records classified as fossils. Additionally, we used the CoordinateCleaner R package to identify potential geographical and temporal errors in species occurrences from GBIF (Zizka et al. 2019). This package flags potential erroneous or duplicate records by identifying occurrences near biodiversity institutions, capital cities, or territory centroids. All flagged records (≈7% of the total records) were removed. GBIF records were complemented with 31,730 records provided by Ibermis (ibermis.org). Shapefiles for the first-level administrative subdivisions for each territory were extracted using the *gadm* function from the geodata R package (Hijmans et al. 2024). Maritime boundaries and Exclusive Economic Zones were extracted from Marine Regions (marineregions.org, Flanders Marine Institute 2023). The total number of non-native species was counted in each main administrative terrestrial subdivision (e.g., Autonomous Communities in Spain or Districts in Portugal) and maritime Exclusive Economic Zones by overlapping species occurrences with their respective polygons. Lastly, we also produced a high-resolution map (Spain and Portugal: 0.045°, Andorra and Gibraltar: 0.005° of resolution) with the number of species occurrences extracted from GBIF. The resolution was chosen for convenience based on the distribution of occurrences from GBIF and the geographical area of the given political entity.

3 | Results

The final dataset recorded a total of 1273 established non-native species in the Iberian Peninsula (Table S3), of which 1034 were present in mainland Spain, 616 in mainland Portugal, 84 in Andorra, and 39 in Gibraltar. The species belonged to 20 phyla (Spain: 19, Portugal: 18, Andorra: 5, Gibraltar: 4), which corresponded to 53 classes (Spain: 49, Portugal: 40, Andorra: 8, Gibraltar: 9) and 374 families (Spain: 329, Portugal: 251, Andorra: 41, Gibraltar: 28). The highest percentage of shared non-native species was recorded in Gibraltar, where 92% of its non-native species were also found in Spain (Figure S1). Similarly, 65% of non-native species in Andorra were also recorded in Spain. Portugal shared nearly three-quarters (65%) of their non-native species with Spain. By contrast, Andorra and Gibraltar shared only two species (5%).

3.1 | Taxonomic Composition

Overall, the taxonomic groups with the most non-native species were vascular plants ($n=727$, e.g., the Pampas grass *Cortaderia seollana*), followed by insects ($n=228$, e.g., the Asian tiger mosquito *Aedes albopictus*), crustaceans ($n=58$, e.g., the red swamp crayfish *Procambarus clarkii*), the 'other invertebrates' category ($n=55$, e.g., the branchiobdellids *Xironogiton victoriensis*), and molluscs ($n=46$, e.g., the zebra mussel *Dreissena polymorpha*) (Figures 1, S1). Spain and Portugal had a similar taxonomic pattern, with vascular plants (Spain: 593, Portugal: 348) and insects (Spain: 170, Portugal: 112) as the most dominant groups, while they differed in the third most represented group, crustaceans in Spain ($n=52$) and 'other invertebrates' in Portugal ($n=28$) (Figure S1). In the case of Andorra, the most dominant groups were vascular plants ($n=73$), and fishes and insects with three and four species each, while in Gibraltar vascular plants dominated ($n=26$), followed by mammals ($n=5$), and insects, birds, and reptiles ($n=2$ each) (Figure S2).

Regarding the taxonomic rank (Figure 1), the most recorded phyla were Tracheophyta (Spain: 593, Portugal: 349), Arthropoda (Spain: 227, Portugal: 139), and Chordata (Spain: 93, Portugal: 56). In Andorra, the dominant phyla recorded were Tracheophyta ($n=73$), Chordata ($n=5$), and Arthropoda ($n=4$), while in Gibraltar, Tracheophyta ($n=26$), Chordata ($n=9$), and Arthropoda ($n=3$) were most prevalent. By taxonomic class, Magnoliopsida was dominant in Spain ($n=449$) and Portugal ($n=265$), followed by Insecta (Spain: 169, Portugal: 111) and Liliopsida (Spain: 133, Portugal: 72). In Andorra, the most recorded classes were Magnoliopsida

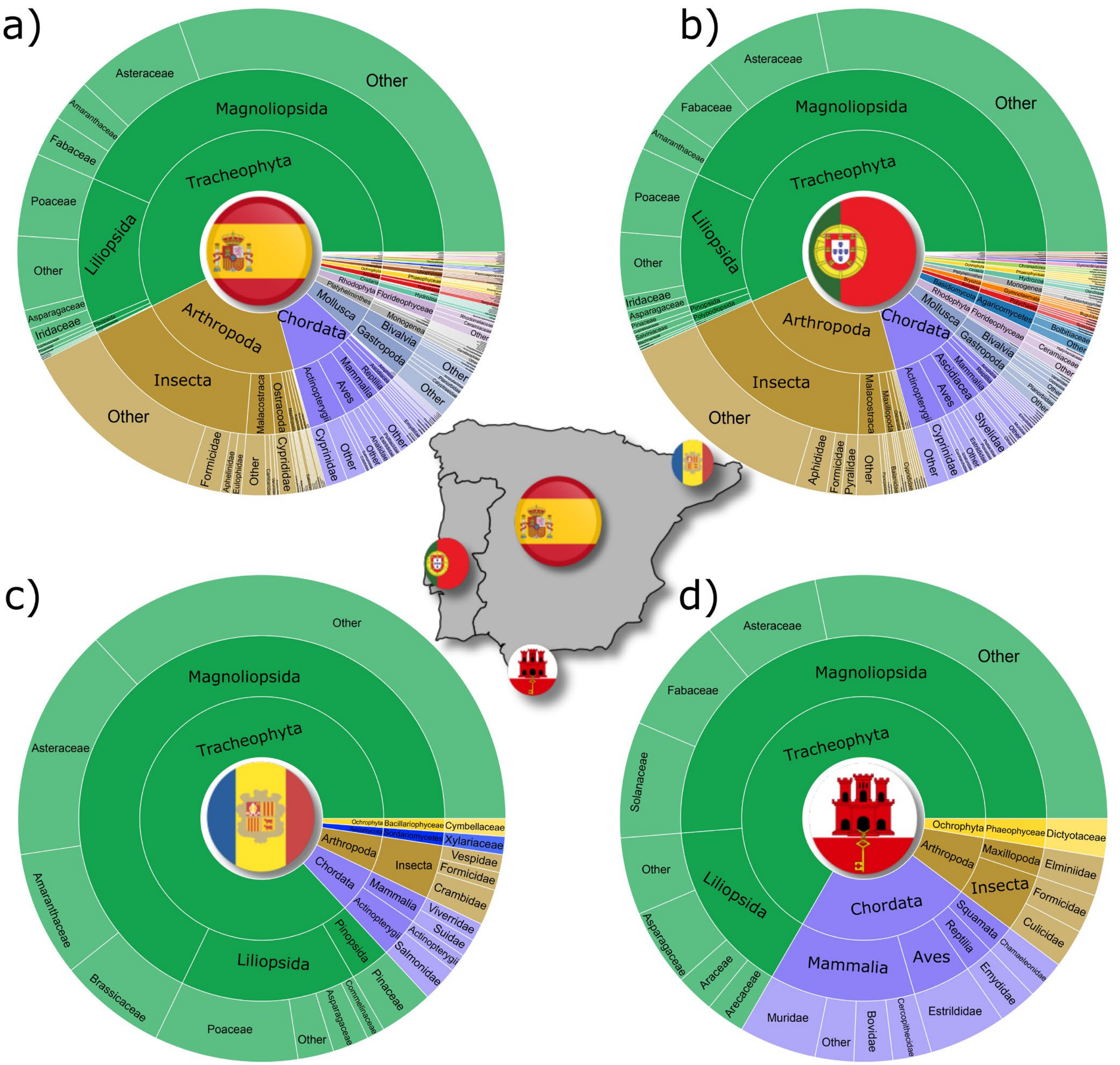

FIGURE 1 | Sunburst charts of the taxonomic diversity of established non-native species in the Iberian Peninsula. Each ring represents a level in the hierarchical taxonomy arranged from the centre outward: Phylum, Class, and Family. Each panel represents one political entity in the Iberian Peninsula: (a) Spain, (b) Portugal, (c) Andorra and (d) Gibraltar. Different colours refer to different Phyla, and radius breadth is proportional to the number of established non-native species. The outer ring of the sunburst represents families, with the top three families (by number of species) per (Phylum, Class) displayed individually and all others grouped as 'Other'. Scales are not comparable across panels, as each chart is independently sized according to the total number of species recorded in each territory.

($n=57$), Liliopsida ($n=13$) and Insecta with four species, while in Gibraltar, Magnoliopsida ($n=20$), Liliopsida ($n=6$) and Mammalia ($n=5$) dominated. Lastly, the top three recorded families—all of them plants—were the same for Spain, Portugal, Andorra, and Gibraltar, although their order differed. In Spain, Asteraceae was the most dominant family ($n=78$), followed by Poaceae and Amaranthaceae ($n=57$ and 29, respectively), whereas in Portugal, Asteraceae ($n=48$) ranked first, followed by Poaceae and Fabaceae ($n=35$ and 28, respectively). In Andorra, the most frequent families were Asteraceae ($n=13$), Poaceae ($n=8$), and Amaranthaceae ($n=4$). In Gibraltar, Asteraceae, Fabaceae, and Solanaceae were the most recorded with three species each.

3.2 | Pathways of Introduction

We recorded pathways of invasion for 76% of non-native species in our dataset (973 species out of 1273), including 243 species (19%) with multiple pathways (i.e., two or more pathways). For instance, some species (e.g., the ducksalad *Heteranthera limosa* and rayed pearl oyster *Pinctada radiata*) used up to five different

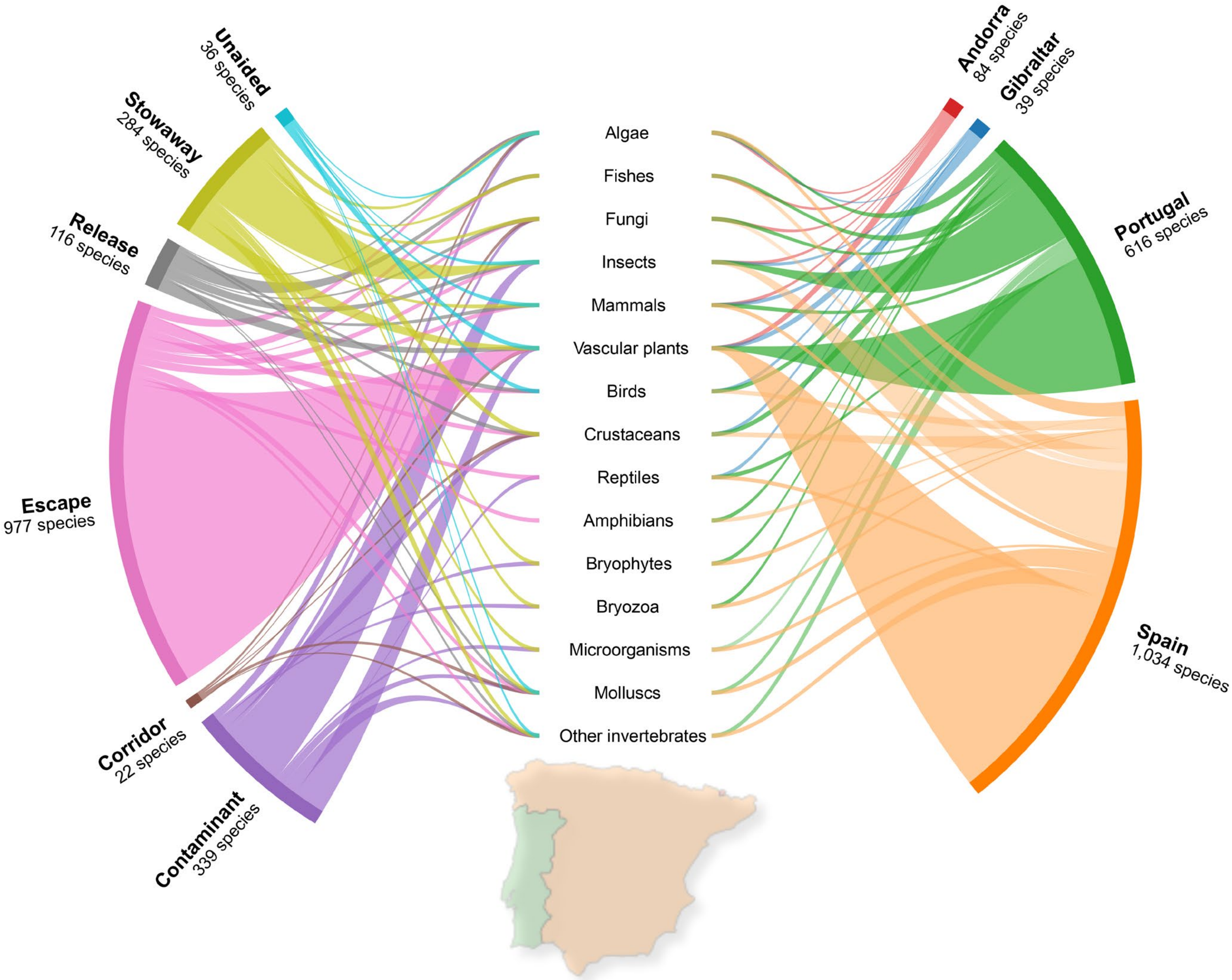

FIGURE 2 | Chord diagram representing the relationships between introduction pathways, taxonomic groups, and political entities for established non-native species recorded in Spain, Portugal, Andorra, and Gibraltar. The width of each link is proportional to the number of species associated with each connection. Specific taxonomic groups–pathway relationship for each political entity can be found in Figure S3.

introduction pathways, where the combination of contaminant and stowaway was the most frequently recorded. At the political entity level, we observed that the most frequent pathways varied, reflecting the differences in taxonomic composition (Figure 2). In Spain and Portugal, the most frequent pathway was 'escape' (Spain: 546, Portugal: 339, Figure S3). This pathway was mainly used by vascular plants, such as Himalayan balsam (*Impatiens glandulifera*) and Canada fleabane (*Erigeron canadensis*). In both cases, they were followed by pathways associated with transport: 'contaminant' (Spain: 198, Portugal: 128) and 'stowaway' (Spain: 166, Portugal: 110). These pathways were mostly associated with insects, such as the Asian hornet (*Vespa velutina*). Other introduction pathways, such as 'corridor' and 'unaided', were less relevant (Figure 2, Figure S3). In Andorra, the most frequent pathways were 'escape' ($n=65$), 'contaminant' ($n=7$), and 'release' ($n=6$). In Gibraltar, the dominant introduction pathway was also 'escape' ($n=25$). This was followed by 'contaminant' and 'stowaway' ($n=6$ and 4, respectively).

3.3 | Native Range

Established non-native species across the Iberian Peninsula predominantly originated from the Palearctic realm ($n=418$), which contributed the largest numbers to all countries: Spain ($n=281$), Portugal ($n=170$), and then to Andorra ($n=44$) and Gibraltar ($n=12$) (Figure 3). In Spain and Portugal, the subsequent contributing realms were ranked in the same order: Nearctic (Spain: 252, Portugal: 132), Neotropical (Spain: 210, Portugal: 116), Afrotropical (Spain: 112, Portugal: 70), Indo-Malayan (Spain: 100, Portugal: 64), and Australasian (Spain: 78, Portugal: 52) (Figure 3a). In Andorra, the Nearctic ($n=18$) and Neotropical ($n=18$) realms provided the largest contributions after the Palearctic, with smaller numbers from the Indo-Malayan ($n=3$) and Afrotropical ($n=2$) (Figure 3c). In Gibraltar, after Palearctic species, they primarily originated from the Neotropical realm ($n=10$), followed by the Afrotropical ($n=7$), Nearctic ($n=5$), Australasian ($n=4$), and Indo-Malayan ($n=2$) realms (Figure 3d).

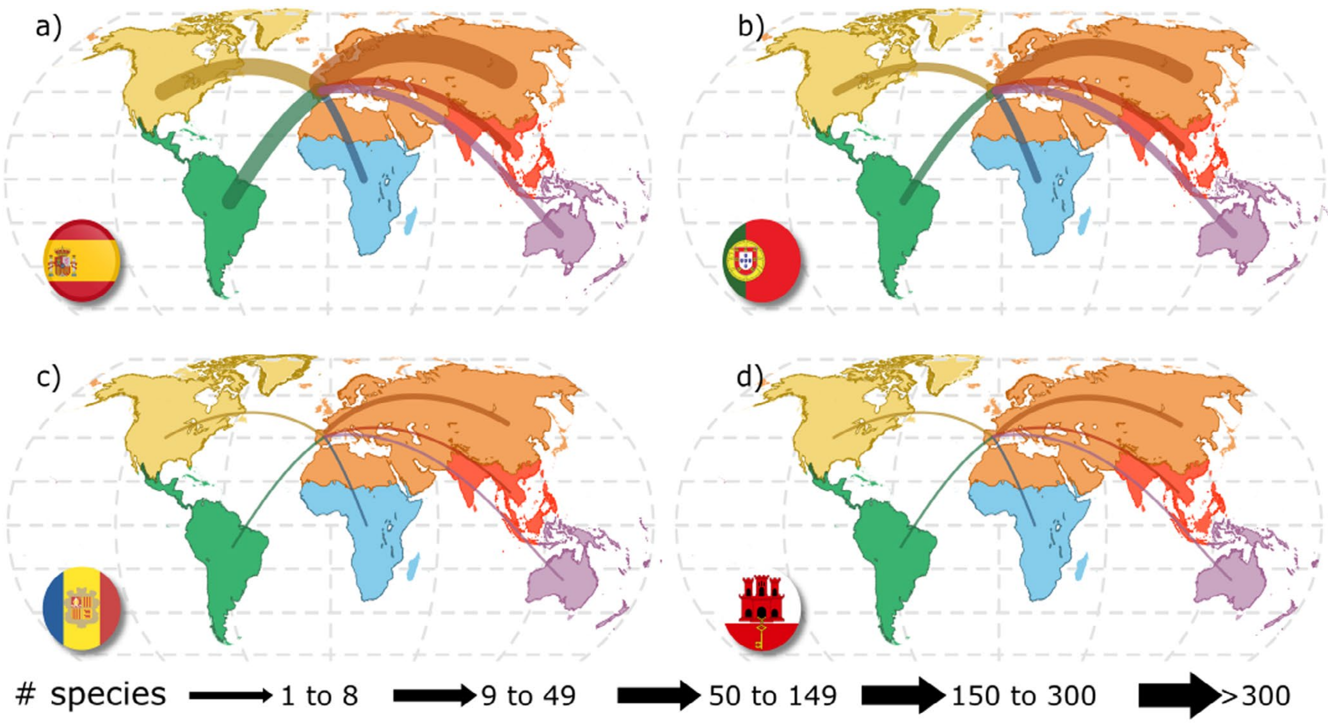

FIGURE 3 | The native regions of established non-native species reported in (a) Spain, (b) Portugal, (c) Andorra, and (d) Gibraltar. The thickness of the lines indicates the number of species (coloured by native realm). Colours represent the different biogeographic realms where species are considered native (Nearctic in yellow, Neotropical in green, Palearctic in orange, Afrotropical in blue, Indo-Malayan in red, Australasian and Oceanian in purple).

3.4 | Temporal Trends of First-Records

The number of annual first records of non-native species increased in the Iberian Peninsula until the last decades of the 20th century, with an apparent decline in recent decades (Figure 4a). Initially, the number of first records was relatively low and only available for Spain and Portugal, with first records from e.g., prickly pear (*Opuntia ficus-indica*) or common fig (*Ficus carica*) in 1500. After the Industrial Revolution (1760–1840), the rate of first records increased significantly, peaking in 1970 in Spain ($n=39$) and 1974 in Portugal ($n=8$). However, in the last decade, the number of new records has sharply declined, reaching levels like those recorded in the 1950s. For Andorra and Gibraltar, the first records were observed in 1962 and 1956, respectively, with a slow increasing trend since then, peaking in 2019 for Andorra and 2020 for Gibraltar. In 1984, Spain surpassed Portugal in the cumulative number of first records (Figure 4b). The cumulative number of first records showed a continuous increase throughout the 20th century, with a sharp acceleration starting around 1970 (Figure 4b).

3.5 | Spatial Distribution

The number of established non-native species across the Iberian Peninsula indicated a high geographic variability (Figure 5a). In Spain, the highest concentrations of established non-native species were in Catalonia, the Valencian Community, and Andalusia, while in Portugal, they were in Lisbon and Coimbra districts (Figure 5b). Notoriously, inland administrative areas had a considerably lower number of established non-native species. The number of non-native species was relatively evenly distributed among the parishes of Andorra, ranging from 4 to 16, although those areas adjacent to the Spanish border (such as Sant Julià de Lòria) contained the highest number of non-native species. In Gibraltar, the highest number of non-native species records was concentrated in the Gibraltar Nature Reserve. In terms of marine habitats, the Mediterranean was the most invaded ($n=625$), followed by the Atlantic Spanish marine area ($n=372$) and lastly, the Portuguese mainland marine area ($n=295$) (Figure 5b). Most GBIF occurrences were concentrated near the capitals and major cities, as well as on the east and south coasts of the Iberian Peninsula.

4 | Discussion

Our results offer critical information for research, policy, management, and conservation, underscoring the need for international collaboration among the political entities within the Iberian Peninsula. This study provides the most comprehensive assessment of established non-native species in the Iberian Peninsula to date, with up to 1273 species identified. Three-quarters of all established species are represented by vascular plants and insects, while one-third of the total originate from the Palearctic realm. Escape from confinement was the dominant pathway of introduction, pointing to the connection of established non-native species to the garden and horticulture trade and ornamental plants cherished in gardens and yards. Temporal trends in annual first records peaked at the end of the 20th century, coinciding with a period of rapid economic growth and liberalisation of trade—likely fuelled by the incorporation of Portugal and Spain into the European Union—followed by a

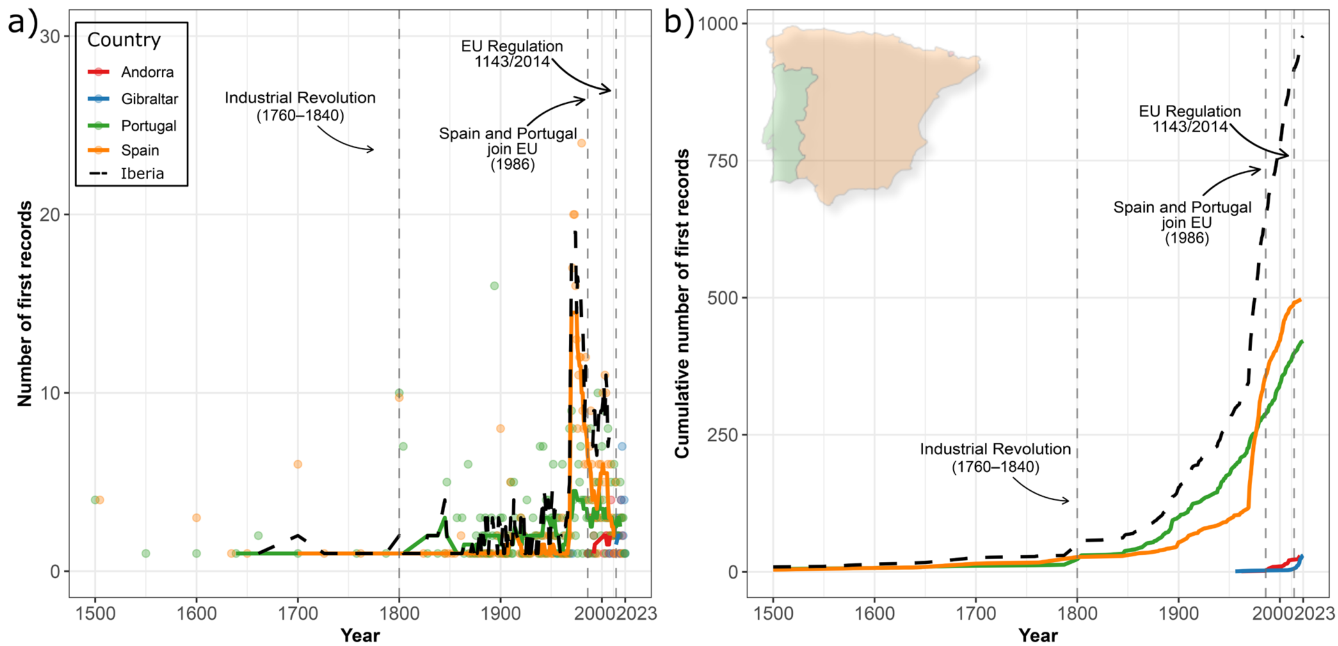

FIGURE 4 | (a) Annual and (b) cumulative number of first records of non-native species in the Iberian Peninsula, and also separately for Spain (orange), Portugal (green), Andorra (red), and Gibraltar (blue). Temporal trends represent a running median with a 10-year moving window. The black dashed line represents the sum of the individual trends of countries of the Iberian Peninsula (i.e., Spain, Portugal, Andorra, and Gibraltar). A focused figure from 1900 to 2023 can be found in the Supporting Information (Figure S4).

decrease in numbers in recent decades. Non-native species were predominantly recorded in urban and coastal areas, emphasising their connection to anthropogenic activities (e.g., urban gardens, urban ponds or maritime ports) and the importance of propagule pressure in the establishment's success (Lockwood et al. 2009) but also that cities and more inhabited areas are preferentially located in pre-existing biodiversity hotspots that are also favourable to non-native species (Kühn et al. 2004).

4.1 | Taxonomic Composition

Understanding the taxonomic composition of non-native species is crucial for developing efficient management strategies (García-Díaz et al. 2022). Due to size differences among political entities, Spain and Portugal host more established non-native species than Andorra and Gibraltar. Overall, vascular plants (Magnoliopsida and Liliopsida) were the most recorded taxonomic group, with numbers over four times those of the next following groups (insects and 'other invertebrates'). Humans have intentionally introduced plants for centuries for agriculture, forestry, ornamental, horticultural, and medical purposes, and still today play a major role in current plant introduction (Pyšek et al. 2009; Van Kleunen et al. 2018). This dominance might also reflect a global pattern of a higher number of non-native plants compared to other groups (IPBES 2023; Briski et al. 2024) possibly amplified by research and detection biases (Pyšek et al. 2009). Plants tend to be easier to detect and monitor because they are sessile, which can lead to their overrepresentation (Perret et al. 2023). Many vascular plants possess traits, such as high reproductive capacity, vegetative propagation, and rapid growth rates, that often give them higher invasiveness compared to other taxonomic groups (Simberloff and Rejmánek 2011). The next species-rich taxonomic groups in Spain and Portugal were insects, crustaceans, and 'other invertebrates'. The causes of the invasion success of insects are multi-factorial, including their ability to be transported over long distances as hitchhikers or through association with plants and soil, high reproductive rates, adaptability, and rapid life cycles (Lockwood et al. 2013). While many crustaceans produce planktonic larvae that disperse widely through ballast waters (Holdich and Pöckl 2007), others are intentionally introduced for economic purposes (e.g., aquaculture, such as red swamp crayfish, Oficialdegui, Sánchez, and Clavero 2020; Oficialdegui et al. 2025). Mammals occupied a notable place in Andorra and Gibraltar, linked with historical introductions (Soto, Balzani, Oficialdegui, et al. 2024). Consequently, the observed taxonomic composition is predominantly shaped by the intentional translocation and deliberate introduction of specific taxonomic groups of interest.

4.2 | Pathways of Introduction

Policies for managing non-native species are often directly linked to the pathways through which these species are introduced (Leung et al. 2014). Escape from human-built confinement structures was the most common—particularly for plants introduced for ornamental and horticultural purposes, but also for pet, aquarium, and terrarium species, as well as farmed animals. This is likely because most non-native plants have been and continue to be cultivated in domestic and botanical gardens (Van Kleunen et al. 2018) and their selected traits for ornamental use, such as rapid and profuse seedling emergence, also increase their likelihood of establishing outside confinement areas (Van Kleunen et al. 2018). The second and third most common pathways were related to transport mechanisms (contaminant and stowaway). These pathways are often used

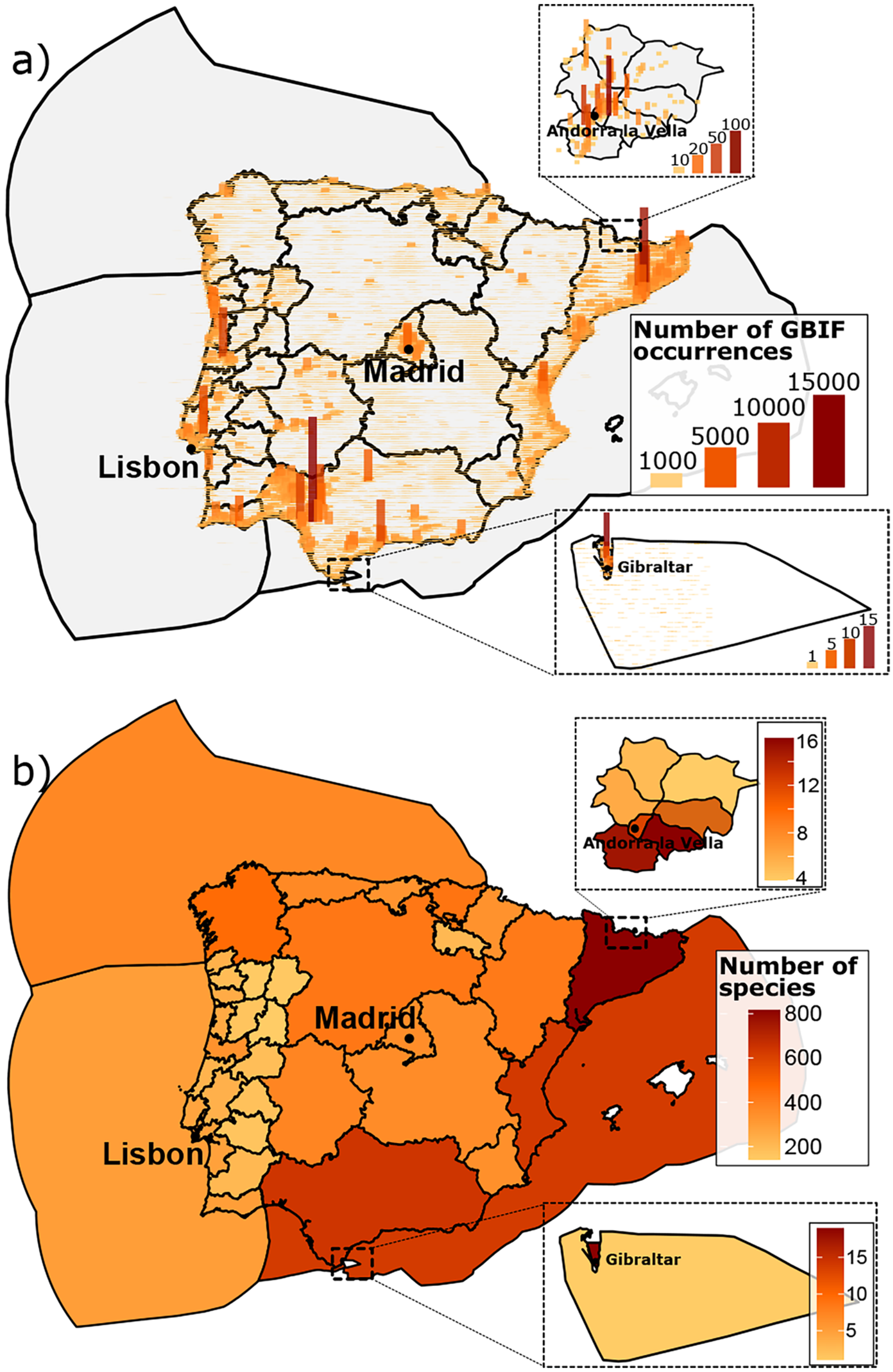

FIGURE 5 | (a) Spike map where each bar represents the number of GBIF occurrences and (b) choropleth map showing the number of species in each administrative area of Spain, Portugal, Andorra and Gibraltar based on GBIF occurrences. Administrative areas were obtained from the geodata R package (Hijmans et al. 2024) and marine Exclusive Economic Zones (solid black line) from Marine Regions (marineregions.org, Flanders Marine Institute 2023). Capital and major cities were sourced from simplemaps.com. Each spike corresponds to a grid cell where the spatial resolution varies across political entities (Spain and Portugal: 0.045°, Andorra and Gibraltar: 0.005° of resolution).

by insects, crustaceans, and other invertebrate species and are associated with the international transport of goods (Kiritani and Yamamura 2003; Ricciardi 2006; Molnar et al. 2008). Additionally, other pathways, such as the movement of military commodities and tourism, also offer opportunities for hitchhiking organisms (Kiritani and Yamamura 2003).

As prevention is the most effective and cost-efficient strategy to manage biological invasions (Leung et al. 2014), intercepting introductions early—at the transport stage—is of great importance. Nevertheless, prevention measures may fail if species remain undetected, highlighting the need for effective monitoring. For instance, monitoring nurseries can prevent the spread of harmful insects and microorganisms (Angulo et al. 2021; Mora-Sala et al. 2022). Consequently, the knowledge of the importance of each pathway helps in decision-making and directing limited resources for managing biological invasions. However, determining the weight of pathways is not an easy task, as many species are not restricted to a single pathway, which reflects the complexity of the relationship between non-native species, pathways, and management (Ruiz and Carlton 2003).

4.3 | Native Origin of Iberian Invasions

The similarities between the native and non-native range of non-native species have been identified as a key driver of invasion success, which also provides insights into potential introduction hotspots (Hejda et al. 2009; Casties et al. 2016; Paiva et al. 2018; Pauli and Briski 2018). Most non-native species in the Iberian Peninsula originate from the Palearctic realm, a pattern likely driven by geographical proximity, shared ecological conditions, and historical human activities (Pyšek et al. 2010; Aymerich and Sáez 2019); indeed, trade routes already existed during the Bronze Age in many parts of the 'Old World' (Boivin 2017). Additionally, the Palearctic realm is the largest of all biogeographical realms—and climatically similar to the Iberian Peninsula—providing the largest potential pool of invaders (García-Berthou et al. 2005; but see differences in Muñoz-Mas and García-Berthou 2020). Nevertheless, some of the most widespread invaders originate from other biogeographic realms (e.g., the red swamp crayfish from the Nearctic and *Acacia* from Australasia). Other biogeographical realms, such as the Nearctic and Neotropical, contributed smaller proportions of non-native species. These introductions are likely influenced by historical Portuguese and Spanish colonialism and modern globalisation (Hudgins et al. 2023). Moreover, climate change and the characteristics of the Iberian Peninsula—especially in the Mediterranean—are creating conditions that are becoming increasingly suitable for tropical and subtropical species. Indeed, new invasions from more distant regions, such as the Indomalayan or Australasian realms, have already been observed in Iberian marine ecosystems (Chainho et al. 2015) and can be expected shortly (Oficialdegui et al. 2023). For instance, the trend toward xerogardening has undoubtedly facilitated the introduction of drought-tolerant succulents from both the Neotropics and the Afrotropics, including genera such as *Agave, Aloe* and *Opuntia* (Salas-Pascual 2021). It is, however, worth noting that our analysis is based on the native origin of the established non-native species, rather than the flow of invasions, as some invasions might come from secondary spread and other non-native areas that acted as stepping-stones (García-Berthou et al. 2005; Capinha et al. 2023).

4.4 | Temporal and Spatial Patterns of Iberian Invasions

Temporally, Spain and Portugal exhibited distinct trends in first records compared to Gibraltar and Andorra. In Spain and Portugal, there was a notable increase in introductions in the late 19th century that accelerated sharply after 1950, coinciding with the 'Spanish miracle', a period of industrialisation and an expansion of trade and transport networks. The sharp decline observed since the 1980s may reflect heightened research efforts and rising awareness (MacIsaac et al. 2011; Lockwood et al. 2013). In the 1980s, corresponding with the publication of the *Scientific Committee on Problems of the Environment* (SCOPE) volumes, scientific interest in biological invasions started to grow. Consequently, many non-native species recorded as established had introductions dating back earlier than previously documented, extending beyond the recent decades of observations (MacIsaac et al. 2011; Lockwood et al. 2013). In the cases of Gibraltar and Andorra, by contrast, a 'minimal' number of first records over time were recorded. This can be attributed to the small size of the countries (often higher countries receive more introductions, García-Berthou et al. 2005), Andorra's geographic isolation and colder climate in the Pyrenees, and its limited involvement in global trade networks compared to Spain and Portugal. Finally, the annual first records in Spain seem to have declined in recent decades (Cobo et al. 2010; but see Muñoz-Mas et al. 2023; Seebens et al. 2021). This contrasts with Portugal, which has shown a steady increase (Anastácio et al. 2019). Nevertheless, awareness is needed, as new non-native species may continue to be recorded regionally and future invaders introduced from their respective native and introduced range may further increase introduction rates artificially.

Administrative regions with high human density and coastal areas exhibited the highest number of non-native species and records, highlighting their role as invasion hotspots, a trend already detected for plants (e.g., Ibáñez et al. 2023). This pattern is closely linked to human activities, such as trade, transport, and urbanisation as drivers of species introductions, along with land-use changes and infrastructure developments that facilitate establishment and dispersal (Cano-Barbacil et al. 2022). Additionally, these activities often attract greater research efforts, supported by the proximity of universities and research centres (see Piccolo et al. 2020). Environmental conditions, such as lowlands and river systems—often near large population centres—favour disturbed habitats that support a higher number of non-native species (Gebauer et al. 2018). Lower densities are observed in the Spanish plateau and the interior areas of Portugal, likely reflecting lower human activity, reduced connectivity and limited pathways for species introductions. Regarding marine areas, the Mediterranean Sea is the most invaded and is considered one of the areas most impacted by non-native species globally (Bailey et al. 2020). Many marine invaders along the Mediterranean coast originate mostly from the Red Sea (e.g., rayed pearl oyster, and ragged sea hare *Bursatella leachii*), facilitated by the opening of the Suez Canal (i.e., Suezian non-native migration, *sensu* Soto, Balzani, Carneiro, et al. 2024).

4.5 | The Role of Legislation

Legislation plays a crucial role in managing biological invasions by providing legally binding frameworks for prevention, early detection, rapid response, control, and mitigation efforts (Genovesi et al. 2015). Despite efforts to establish legislative instruments, such as the List of invasive alien species of Union concern at the European level (Union list, Regulation No. 1143/2014) and others at the national levels (e.g., Decret 258/2022, del 15-6-2022, d'aprovació del Reglament d'espècies exòtiques invasores in Andorra), ineffective enforcement of these regulations could undermine biodiversity conservation targets. Tollington et al. (2017) identified the lack of funding mechanisms and weak collaboration among stakeholders as key risks to the effectiveness of European legislation. However, it is worth highlighting that a significant effort to build legal tools has been conducted in recent years, with several management, control, and eradication strategies for certain species or groups of invasive species having been implemented (e.g., American mink, zebra mussel, water hyacinth, or snakes on islands; miteco.gob.es/es/biodiversidad/temas/conservacion-de-especies/especies-exoticas-invasoras/ce-eei-estrategia-planes.html, icnf.pt/conservacao/especiesexoticas/especiesexoticasinvasoras/eeicontrolocontencaoerradicacao). While legislative improvements and periodic updates are always necessary—especially given the evolving nature of biological invasions—the primary challenge remains to ensure that existing laws are properly implemented and enforced (Oficialdegui, Delibes-Mateos, et al. 2020).

4.6 | Caveats

While we provided the most comprehensive analysis of established non-native species in the Iberian Peninsula, it remains subject to well-known biases and uncertainties inherent in biodiversity databases, such as research focus on well-studied and large-sized taxa, and the uneven spatial distribution of recording effort (Beck et al. 2014; Rocha-Ortega et al. 2021; Bowler et al. 2022). Taxonomically, groups like fungi, microorganisms, and invertebrates are likely underreported due to the harder detectability, lack of taxonomic expertise, and consequent lack of historical research on these groups (Desprez-Loustau et al. 2007; Briski et al. 2024). Spatially, GBIF occurrences are often unevenly reported, primarily due to spatially biased sampling efforts concentrated near densely populated areas and may include errors arising from the integration of multiple data sources. Nonetheless, the broader taxonomic and spatial coverage offered by citizen science and other platforms justifies their inclusion and enhances the robustness of the overall analysis (Beck et al. 2014). Biases are particularly evident in open marine areas and understudied inland regions, highlighting the need for more comprehensive surveys and monitoring programmes, particularly in aquatic environments. The accuracy of historical species' first records is also often highly variable, potentially affecting the observed trends (Carlton and Schwindt 2024). Additionally, integrating multiple databases and sources is always challenging due to the different metadata and terminology used, which may have resulted in some inconsistencies or the inclusion/exclusion of some species. Despite these biases, our study remains a valuable and comprehensive contribution to understanding the patterns and drivers of established non-native species in the Iberian Peninsula, providing a baseline for future research.

5 | Conclusions

Our results not only complement previous studies but also provide a foundation for future research by refining the database and analyses, as well as offering valuable insights for research, policy, and conservation management. We identified invasion hotspots, enabling management efforts to focus on these areas to control current invasions and prevent secondary invasions. The continuous advancement of technologies, such as environmental DNA, remote sensing, and social media data mining, will improve our ability to detect, track, and manage non-native species. In addition, promoting citizen science and public outreach will help facilitate early detection and rapid response efforts, which should be accompanied by robust enforcement and legal application of current laws regarding non-native species. The Iberian Peninsula is already recognised as a hotspot for biological invasions—as shown in this study—and the situation is likely to worsen shortly, as this area is projected to experience among the most severe climatic changes in Europe (Herrando-Moraira et al. 2022). We emphasise the need for international collaboration within and among the political entities of the Iberian Peninsula to effectively mitigate the impacts of biological invasions. While some collaborative programmes existed—such as LIFE INVASAQUA (López-Cañizares et al. 2025)—these efforts should be further enhanced and reinforced to maximise their effectiveness across the entire Peninsula.

Author Contributions

Conceptualization: Ismael Soto, Francisco J. Oficialdegui, and Sergio Bedmar. Data curation: All authors have contributed. Formal analysis: Ismael Soto. Writing – original draft: Ismael Soto, Francisco J. Oficialdegui, and Sergio Bedmar. Writing – review and editing: all authors have contributed.

Acknowledgements

R.S. was supported by the Portuguese Foundation for Science and Technology (FCT) through national funds under the project MULTI-CRASH: Multi-dimensional ecological cascades triggered by an invasive species in pristine habitats (PTDC/CTA-AMB/0510/2021) (https://doi.org/10.54499/PTDC/CTA-AMB/0510/2021). F.R. is supported by an individual contract from FCT (CEEC/0482/2020) and by the project MEGAPREDATOR: A giant on the water: from predation pressure to population control of the European catfish (Silurus glanis) (https://doi.org/10.54499/PTDC/ASP-PES/4181/2021). E.G.B. and C.M.M. received financial support from the Spanish Ministry of Science, Innovation, and Universities (MICIU/AEI/https://doi.org/10.13039/501100011033) and the European Union (NextGenerationEU/PRTR) through projects TED2021-129889B-I00, RED2022-134338-T, and PID2023-146173NB-C21. C.C.-B. and C.M.M. benefited from postdoctoral contracts (ref. JDC2023-052358-I and FJC2021-047559-I, respectively), funded by the Spanish Ministry of Science, Innovation, and Universities, the Agencia Estatal de Investigación (MICIU/AEI/10.13039/501100011033) and the FSE+. C.C. acknowledges funding from FCT through InvaSTOP research grant (https://doi.org/10.54499/2023.12533.PEX) and through funds to CEG/IGOT Research Unit (UIDB/00295/2020 and UIDP/00295/2020). C.A. is supported by a predoctoral grant, "Formación de Personal Investigador" (PRE2020-094732) associated to the ClimaRiskinPond proyect (PID2019-104580GA-100) funded by MCIN/AEI/10.13039/501100011033 and the European Social Fund. P.M.A. is financed by Fundação para a Ciência e Tecnologia through the strategic project UIDB/04292/2020 awarded to Centro de Ciências do Mar e do Ambiente and through project LA/P/0069/2020 granted to the Associated Laboratory Rede de Investigação Aquática. J.L.-P. is supported by the Ministerio de Ciencia e Innovación, Spain (project PID2020-119163GB-I00 funded by MCIN/AEI/10.13039/501100011033). M.F. has a contract RyC2022-036451-I funded by MICIU/AEI/10.13039/501100011033 and by ESF+; Agencia Estatal de Investigación; Ministerio de Ciencia, Innovación y Universidades. S.B. is supported by the through the project CRAYMAP (Crayfish invasions across time and space, a multidisciplinary approach, PID2020-20026RB-I00) funded by the Spanish Ministry of Science and Innovation. P.J.H. was supported by the Marie Skłodowska-Curie Postdoctoral Fellowship HORIZON-MSCA-2022-PF-01 (Project DIRECT; Grant No. 101203662) within the European Union's Horizon 2022 research and innovation programme.

Conflicts of Interest

Elizabeta Briski and César Capinha are editors of Diversity & Distributions but were not involved in the review or decision-making process for this manuscript.

Data Availability Statement

All data generated and analysed during this study are publicly available and can be accessed at GitHub (https://github.com/IsmaSA/Iberia_NNS).

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ddi.70071.

References

Acevedo-Limón, L., F. J. Oficialdegui, M. I. Sánchez, and M. Clavero. 2020. "Historical, Human, and Environmental Drivers of Genetic Diversity in the Red Swamp Crayfish (*Procambarus clarkii*) Invading the Iberian Peninsula." *Freshwater Biology* 65, no. 8: 1460–1474.

Aedo, C., A. Buira, L. Medina, and M. Fernández-Albert. 2017. "The Iberian Vascular Flora: Richness, Endemicity and Distribution Patterns." In *The Vegetation of the Iberian Peninsula*, 101–130. Springer.

Aedo, C., L. Medina, and M. Fernández-Albert. 2013. "Species Richness and Endemicity in the Spanish Vascular Flora." *Nordic Journal of Botany* 31, no. 4: 478–488.

Anastácio, P. M., F. Ribeiro, C. Capinha, et al. 2019. "Non-Native Freshwater Fauna in Portugal: A Review." *Science of the Total Environment* 650: 1923–1934.

Angulo, E., L. Ballesteros-Mejia, A. Novoa, V. G. Duboscq-Carra, C. Diagne, and F. Courchamp. 2021. "Economic Costs of Invasive Alien Species in Spain." *NeoBiota* 67: 267–297.

Ascensão, F., M. D'Amico, R. C. Martins, et al. 2021. "Distribution of Alien Tetrapods in the Iberian Peninsula." *NeoBiota* 64: 1–21.

Aymerich, P., and L. Sáez. 2019. "Checklist of the Vascular Alien Flora of Catalonia (Northeastern Iberian Peninsula, Spain)." *Mediterranean Botany* 40, no. 2: 215–242.

Bailey, S. A., L. Brown, M. L. Campbell, et al. 2020. "Trends in the Detection of Aquatic Non-Indigenous Species Across Global Marine, Estuarine and Freshwater Ecosystems: A 50-Year Perspective." *Diversity and Distributions* 26, no. 12: 1780–1797.

Baquero, R. A., and J. L. Tellería. 2001. "Species Richness, Rarity and Endemicity of European Mammals: A Biogeographical Approach." *Biodiversity and Conservation* 10, no. 1: 29–44.

Beck, J., M. Böller, A. Erhardt, and W. Schwanghart. 2014. "Spatial Bias in the GBIF Database and Its Effect on Modeling Species' Geographic Distributions." *Ecological Informatics* 19: 10–15.

Bellard, C., P. Cassey, and T. M. Blackburn. 2016. "Alien Species as a Driver of Recent Extinctions." *Biology Letters* 12, no. 2: 20150623.

Blackburn, T. M., P. Pyšek, S. Bacher, et al. 2011. "A Proposed Unified Framework for Biological Invasions." *Trends in Ecology & Evolution* 26, no. 7: 333–339.

Boivin, N. 2017. "Proto-Globalisation and Biotic Exchange in the Old World." *Human Dispersal and Species Movement From Prehistory to the Present* 1: 349–408.

Bowler, D. E., C. T. Callaghan, N. Bhandari, et al. 2022. "Temporal Trends in the Spatial Bias of Species Occurrence Records." *Ecography* 2022, no. 8: e06219.

Briski, E., S. G. Kotronaki, N. R. Cuthbert, et al. 2024. "Does Non-Native Diversity Mirror Earth's Biodiversity?" *Global Ecology and Biogeography* 33: 48–62. https://doi.org/10.1111/geb.13781.

Cano-Barbacil, C., J. Radinger, and E. García-Berthou. 2022. "The Importance of Seawater Tolerance and Native Status in Mediating the Distribution of Inland Fishes." *Journal of Biogeography* 49, no. 11: 2037–2049.

Capinha, C., F. Essl, M. Porto, and H. Seebens. 2023. "The Worldwide Networks of Spread of Recorded Alien Species." *Proceedings of the National Academy of Sciences of the United States of America* 120, no. 1: e2201911120.

Capinha, C., F. Essl, H. Seebens, D. Moser, and H. M. Pereira. 2015. "The Dispersal of Alien Species Redefines Biogeography in the Anthropocene." *Science* 348, no. 6240: 1248–1251.

Carlton, J. T., and E. Schwindt. 2024. "The Assessment of Marine Bioinvasion Diversity and History." *Biological Invasions* 26, no. 1: 237–298.

Casties, I., H. Seebens, and E. Briski. 2016. "Importance of Geographic Origin for Invasion Success: A Case Study of the North and Baltic Seas Versus the Great Lakes–St. Lawrence River Region." *Ecology and Evolution* 6, no. 22: 8318–8329.

CBD. 2014. *Pathways of Introduction of Invasive Species, Their Prioritization and Management*. In UNEP/CBD/SBSTTA/18/9/Add. 1. Secretariat of the Convention on Biological Diversity.

Cerri, J., L. Carnevali, A. Monaco, P. Genovesi, and S. Bertolino. 2022. "Blacklists Do Not Necessarily Make People Curious About Invasive Alien Species. A Case Study With Bayesian Structural Time Series and Wikipedia Searches About Invasive Mammals in Italy." *NeoBiota* 71: 113–128.

Chainho, P., A. Fernandes, A. Amorim, et al. 2015. "Non-Indigenous Species in Portuguese Coastal Areas, Coastal Lagoons, Estuaries and Islands." *Estuarine, Coastal and Shelf Science* 167: 199–211.

Chamberlain, S., K. Ram, V. Barve, D. Mcglinn, and M. S. Chamberlain. 2017. "Package 'Rgbif'." Interface to the Global Biodiversity Information Facility API, 5(0.9).

Clavero, M., and E. García-Berthou. 2005. "Invasive Species Are a Leading Cause of Animal Extinctions." *Trends in Ecology & Evolution* 20, no. 3: 110.

Clavero, M., and E. García-Berthou. 2006. "Homogenization Dynamics and Introduction Routes of Invasive Freshwater Fish in the Iberian Peninsula." *Ecological Applications* 16, no. 6: 2313–2324.

Cobo, F., R. Vieira-Lanero, E. Rego, and M. J. Servia. 2010. "Temporal Trends in Non-Indigenous Freshwater Species Records During the 20th Century: A Case Study in the Iberian Peninsula." *Biodiversity and Conservation* 19: 3471–3487.

Crosby, A. W., Jr. 2003. *The Columbian Exchange: Biological and Cultural Consequences of 1492*. Bloomsbury Publishing.

Dawson, W., J. M. Peyton, O. L. Pescott, et al. 2023. "Horizon Scanning for Potential Invasive Non-Native Species Across the United Kingdom Overseas Territories." *Conservation Letters* 16, no. 1: e12928.

Desprez-Loustau, M. L., C. Robin, M. Buee, et al. 2007. "The Fungal Dimension of Biological Invasions." *Trends in Ecology & Evolution* 22, no. 9: 472–480.

Diagne, C., B. Leroy, A. C. Vaissière, et al. 2021. "High and Rising Economic Costs of Biological Invasions Worldwide." *Nature* 592, no. 7855: 571–576.

Ehrenfeld, J. G. 2010. "Ecosystem Consequences of Biological Invasions." *Annual Review of Ecology, Evolution, and Systematics* 41, no. 1: 59–80.

Fernandes, R., A. Castro, H. Marchante, E. Marchante, and C. Capinha. 2025. "Distribution Patterns of Invasive Alien Plant Species in Mainland Portugal." *bioRxiv* 1: 202506.

Flanders Marine Institute. 2023. "Maritime Boundaries Geodatabase: Maritime Boundaries and Exclusive Economic Zones (200NM), Version 12." https://www.marineregions.org/.

Gallardo, B., M. Clavero, M. I. Sánchez, and M. Vilà. 2016. "Global Ecological Impacts of Invasive Species in Aquatic Ecosystems." *Global Change Biology* 22, no. 1: 151–163.

García-Berthou, E., C. Alcaraz, Q. Pou-Rovira, L. Zamora, G. Coenders, and C. Feo. 2005. "Introduction Pathways and Establishment Rates of Invasive Aquatic Species in Europe." *Canadian Journal of Fisheries and Aquatic Sciences* 62, no. 2: 453–463.

García-Díaz, P., L. Montti, P. A. Powell, et al. 2022. "Identifying Priorities, Targets, and Actions for the Long-Term Social and Ecological Management of Invasive Non-Native Species." *Environmental Management* 69, no. 1: 140–153.

Gassó, N., W. Thuiller, J. Pino, and M. Vilà. 2012. "Potential Distribution Range of Invasive Plant Species in Spain." *NeoBiota* 12: 25–40.

GBIF.org. 2023. "GBIF Home Page." https://www.gbif.org.

GBIF.org. 2025a. "GBIF Occurrence Download." https://doi.org/10.15468/dl.288tta. Accessed From R via Rgbif. https://github.com/ropensci/rgbif on 2025-07-15.

GBIF.org. 2025b. "GBIF Occurrence Download." https://doi.org/10.15468/dl.3xgaj9. Accessed From R via Rgbif. https://github.com/ropensci/rgbif on 2025-07-15.

GBIF.org. 2025c. "GBIF Occurrence Download." https://doi.org/10.15468/dl.v7bpy9. Accessed From R via Rgbif. https://github.com/ropensci/rgbif on 2025-07-15.

Gebauer, R., J. Divíšek, M. Buřič, M. Večeřa, A. Kouba, and B. Drozd. 2018. "Distribution of Alien Animal Species Richness in The Czech Republic." *Ecology and Evolution* 8, no. 9: 4455–4464.

Genovesi, P., C. Carboneras, M. Vila, and P. Walton. 2015. "EU Adopts Innovative Legislation on Invasive Species: A Step Towards a Global Response to Biological Invasions?" *Biological Invasions* 17: 1307–1311.

Gómez, A., and D. H. Lunt. 2007. "Refugia Within Refugia: Patterns of Phylogeographic Concordance in the Iberian Peninsula." In *Phylogeography of Southern European Refugia: Evolutionary Perspectives on the Origins and Conservation of European Biodiversity*, 155–188. Springer Netherlands.

Gutiérrez, J. L., C. G. Jones, and R. Sousa. 2014. "Toward an Integrated Ecosystem Perspective of Invasive Species Impacts." *Acta Oecologica* 54: 131–138.

Haubrock, P. J., P. Balzani, R. Macêdo, and A. S. Tarkan. 2023. "Is the Number of Non-Native Species in the European Union Saturating?" *Environmental Sciences Europe* 35, no. 1: 48.

Hejda, M., P. Pyšek, J. Pergl, J. Sádlo, M. Chytrý, and V. Jarošík. 2009. "Invasion Success of Alien Plants: Do Habitat Affinities in the Native Distribution Range Matter?" *Global Ecology and Biogeography* 18, no. 3: 372–382.

Henry, M., B. Leung, R. N. Cuthbert, et al. 2023. "Unveiling the Hidden Economic Toll of Biological Invasions in the European Union." *Environmental Sciences Europe* 35, no. 1: 43.

Herrando-Moraira, S., N. Nualart, M. Galbany-Casals, et al. 2022. "Climate Stability Index Maps, a Global High Resolution Cartography of Climate Stability From Pliocene to 2100." *Scientific Data* 9, no. 1: 48.

Hijmans, R. J., M. Barbosa, A. Ghosh, and A. Mandel. 2024. "Geodata: Download Geographic Data. R Package Version 0.6–2." https://github.com/rspatial/geodata.

Holdich, D., and M. Pöckl. 2007. "Invasive Crustaceans in European Inland Waters." In *Biological Invaders in Inland Waters: Profiles, Distribution, and Threats*, edited by F. Gherardi, 29–75. Springer.

Hudgins, E. J., R. N. Cuthbert, P. J. Haubrock, et al. 2023. "Unevenly Distributed Biological Invasion Costs Among Origin and Recipient Regions." *Nature Sustainability* 6, no. 9: 1113–1124.

Ibáñez, N., C. Gómez-Bellver, P. Farelo, et al. 2023. "Montjuïc Hill (Barcelona): A Hotspot for Plant Invasions in a Mediterranean City." *Plants* 12, no. 14: 2713.

IPBES. 2023. *Thematic Assessment Report on Invasive Alien Species and Their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*, edited by H. E. Roy, A. Pauchard, P. Stoett, and T. Renard Truong. IPBES Secretariat.

Kiritani, K., and K. Yamamura. 2003. "Exotic Insects and Their Pathways for Invasion." In *Invasive Species—Vectors and Management Strategies*, edited by G. M. Ruiz and J. T. Carlton, 44–67. Island Press.

Kühn, I., R. Brandl, and S. Klotz. 2004. "The Flora of German Cities is Naturally Species Rich." *Evolutionary Ecology Research* 6, no. 5: 749–764.

Lázaro-Lobo, A., J. A. Campos, T. E. D. González, et al. 2024. "An Ecoregion-Based Approach to Evaluate Invasive Plant Species Pools." *NeoBiota* 96: 105–128.

Leprieur, F., S. Brosse, E. Garcia-Berthou, T. Oberdorff, J. D. Olden, and C. R. Townsend. 2009. "Scientific Uncertainty and the Assessment of Risks Posed by Non-Native Freshwater Fishes." *Fish and Fisheries* 10, no. 1: 88–97.

Leung, B., M. R. Springborn, J. A. Turner, and E. G. Brockerhoff. 2014. "Pathway-Level Risk Analysis: The Net Present Value of an Invasive Species Policy in the US." *Frontiers in Ecology and the Environment* 12, no. 5: 273–279.

Lockwood, J. L., P. Cassey, and T. M. Blackburn. 2009. "The More You Introduce the More You Get: The Role of Colonization Pressure and Propagule Pressure in Invasion Ecology." *Diversity and Distributions* 15, no. 5: 904–910.

Lockwood, J. L., M. F. Hoopes, and M. P. Marchetti. 2013. *Invasion Ecology*. John Wiley & Sons.

López-Cañizares, C., R. Olivo del Amo, A. Guillén-Beltrán, et al. 2025. "Outcomes of the LIFE INVASAQUA Project: An Integrated Approach for the Prevention and Awareness of Aquatic Invasive Species in the Iberian Peninsula." *NeoBiota*.

MacIsaac, H. J., R. A. Tedla, and A. Ricciardi. 2011. "Patterns and Rate of Growth of Studies in Invasion Ecology." In *Fifty Years of Invasion Ecology: The Legacy of Charles Elton*, edited by D. M. Richardson, 51–60. Wiley-Blackwell.

Marchante, H., M. Morais, H. Freitas, and E. Marchante. 2014. *Guia Prático Para a Identificação de Plantas Invasoras em Portugal*. Imprensa da Universidade de Coimbra/Coimbra University Press.

Miguel, I., M. Iriondo, L. Garnery, W. S. Sheppard, and A. Estonba. 2007. "Gene Flow Within the M Evolutionary Lineage of *Apis mellifera*: Role of the Pyrenees, Isolation by Distance and Post-Glacial Re-Colonization Routes in the Western Europe." *Apidologie* 38, no. 2: 141–155.

Molnar, J. L., R. L. Gamboa, C. Revenga, and M. D. Spalding. 2008. "Assessing the Global Threat of Invasive Species to Marine Biodiversity." *Frontiers in Ecology and the Environment* 6, no. 9: 485–492.

Mora-Sala, B., M. León, A. Pérez-Sierra, and P. Abad-Campos. 2022. "New Reports of *Phytophthora* Species in Plant Nurseries in Spain." *Pathogens* 11, no. 8: 826.

Muñoz-Mas, R., F. Essl, M. van Kleunen, et al. 2023. "Two Centuries of Spatial and Temporal Dynamics of Freshwater Fish Introductions." *Global Ecology and Biogeography* 32: 1632–1644.

Muñoz-Mas, R., and E. García-Berthou. 2020. "Alien Animal Introductions in Iberian Inland Waters: An Update and Analysis." *Science of the Total Environment* 703: 134505.

Oficialdegui, F. J., M. Delibes-Mateos, A. J. Green, M. I. Sánchez, L. Boyero, and M. Clavero. 2020. "Rigid Laws and Invasive Species Management." *Conservation Biology* 34, no. 4: 1047–1050.

Oficialdegui, F. J., M. I. Sánchez, and M. Clavero. 2020. "One Century Away From Home: How the Red Swamp Crayfish Took Over the World." *Reviews in Fish Biology and Fisheries* 30, no. 1: 121–135.

Oficialdegui, F. J., I. Soto, P. Balzani, et al. 2025. "Non-Native Species in Aquaculture: Burgeoning Production and Environmental Sustainability Risks." *Reviews in Aquaculture* 17, no. 3: e70037.

Oficialdegui, F. J., J. M. Zamora-Marín, S. Guareschi, et al. 2023. "A Horizon Scan Exercise for Aquatic Invasive Alien Species in Iberian Inland Waters." *Science of the Total Environment* 869: 161798.

Oliva-Paterna, F. J., F. Ribeiro, R. Miranda, et al. 2020. "Lista de Especies Exóticas Acuáticas de la Península Ibérica." Lista Actualizada de las Especies Exóticas Acuáticas Introducidas y Establecidas en Las Aguas Continentales Ibéricas. Informe Técnico Preparado por Life Invasaqua (LIFE17 GIE/ES/000515), 64.

Olson, D. M., E. Dinerstein, E. D. Wikramanayake, et al. 2001. "Terrestrial Ecoregions of the World: A New Map of Life on Earth: A New Global Map of Terrestrial Ecoregions Provides an Innovative Tool for Conserving Biodiversity." *Bioscience* 51, no. 11: 933–938.

Pagad, S., P. Genovesi, L. Carnevali, D. Schigel, and M. A. McGeoch. 2018. "Introducing the Global Register of Introduced and Invasive Species." *Scientific Data* 5, no. 1: 170202.

Paiva, F., A. Barco, Y. Chen, et al. 2018. "Is Salinity an Obstacle for Biological Invasions?" *Global Change Biology* 24, no. 6: 2708–2720.

Pauli, N. C., and E. Briski. 2018. "Euryhalinity of Ponto-Caspian Invaders in Their Native and Introduced Regions." *Aquatic Invasions* 13, no. 4: 439–447.

Perez De Tudela, A. P., and A. J. Gschwend. 2007. "Renaissance Menageries. Exotic Animals and Pets at the Habsburg Courts in Iberia and Central Europe." *Early Modern Zoology: The Construction of Animals in Science, Literature and the Visual Arts* 2: 419–447.

Perret, J., A. Besnard, A. Charpentier, and G. Papuga. 2023. "Plants Stand Still but Hide: Imperfect and Heterogeneous Detection Is the Rule When Counting Plants." *Journal of Ecology* 111, no. 7: 1483–1496.

Piccolo, R. L., J. Warnken, A. L. Chauvenet, and J. G. Castley. 2020. "Location Biases in Ecological Research on Australian Terrestrial Reptiles." *Scientific Reports* 10, no. 1: 1–10.

Pyšek, P., S. Bacher, M. Chytrý, et al. 2010. "Contrasting Patterns in the Invasions of European Terrestrial and Freshwater Habitats by Alien Plants, Insects and Vertebrates." *Global Ecology and Biogeography* 19, no. 3: 317–331.

Pyšek, P., P. W. Lambdon, M. Arianoutsou, I. Kühn, J. Pino, and M. Winter. 2009. "Alien Vascular Plants of Europe." In *Handbook of Alien Species in Europe*, 43–61. Springer.

Ribeiro, F., M. J. Collares-Pereira, and P. B. Moyle. 2009. "Non-Native Fish in the Fresh Waters of Portugal, Azores and Madeira Islands: A Growing Threat to Aquatic Biodiversity." *Fisheries Management and Ecology* 16, no. 4: 255–264.

Ricciardi, A. 2006. "Patterns of Invasion in the Laurentian Great Lakes in Relation to Changes in Vector Activity." *Diversity and Distributions* 12, no. 4: 425–433.

Ricciardi, A. 2007. "Are Modern Biological Invasions an Unprecedented Form of Global Change?" *Conservation Biology* 21, no. 2: 329–336.

Rocha-Ortega, M., P. Rodriguez, and A. Córdoba-Aguilar. 2021. "Geographical, Temporal and Taxonomic Biases in Insect GBIF Data on Biodiversity and Extinction." *Ecological Entomology* 46, no. 4: 718–728.

Ruiz, G. M., and J. T. Carlton. 2003. *Invasive Species: Vectors and Management Strategies*, 459–518. Island Press.

Ruzafa, A. 2011. "Flora al·lòctona d'Andorra. Avaluació de Risc d'Invasió i d'Idoneïtat d'Establiment per a Tres Espècies Significatives." Treball Final de Carrera, Universitat de Lleida. Departament de Medi Ambient, Departament d'Innovació i Recerca del Govern d'Andorra, Centre D'estudis de la Neu i de la Muntanya d'Andorra (CENMA) de l'Institut d'Estudis Andorrans (IEA), 292.

Saffer, A., T. Worm, Y. Takeuchi, and R. Meentemeyer. 2024. "GIataR: A Spatio-Temporal Dataset of Global Invasive and Alien Species and Their Traits." *Scientific Data* 11, no. 1: 991.

Salas-Pascual, M. 2021. "Potencial Invasor de Las Cactáceas y Otras Plantas Crasas." *Conservación Vegetal* 25: 45–47.

Seebens, H., S. Bacher, T. M. Blackburn, et al. 2021. "Projecting the Continental Accumulation of Alien Species Through to 2050." *Global Change Biology* 27, no. 5: 970–982.

Seebens, H., T. M. Blackburn, E. E. Dyer, et al. 2017. "No Saturation in the Accumulation of Alien Species Worldwide." *Nature Communications* 8, no. 1: 14435.

Seebens, H., D. A. Clarke, Q. Groom, et al. 2020. "A Workflow for Standardising and Integrating Alien Species Distribution Data." *NeoBiota* 59: 39–59.

Sérgio, C., M. Brugués, R. M. Cros, C. Casas, and C. Garcia. 2007. "The 2006 Red List and an Updated Checklist of Bryophytes of the Iberian Peninsula (Portugal, Spain and Andorra)." *Lindbergia* 31: 109–125.

Simberloff, D. 2013. *Invasive Species: What Everyone Needs to Know*. Oxford University Press.

Simberloff, D., and M. Rejmánek, eds. 2011. *Encyclopedia of Biological Invasions*. Univ of California Press.

Soto, I., P. Balzani, L. Carneiro, et al. 2024. "Taming the Terminological Tempest in Invasion Science." *Biological Reviews* 99: 1357–1390.

Soto, I., P. Balzani, F. J. Oficialdegui, et al. 2024. "The Wild Cost of Invasive Feral Animals Worldwide." *Science of the Total Environment* 912: 169281.

Soto, I., P. Courtois, A. Pili, et al. 2025. "Using Species Ranges and Macroeconomic Data to Fill the Gap in Costs of Biological Invasions." *Nature Ecology & Evolution* 9: 1–1030.

Tollington, S., A. Turbe, W. Rabitsch, et al. 2017. "Making the EU Legislation on Invasive Species a Conservation Success." *Conservation Letters* 10, no. 1: 112–120.

Van Kleunen, M., F. Essl, J. Pergl, et al. 2018. "The Changing Role of Ornamental Horticulture in Alien Plant Invasions." *Biological Reviews* 93, no. 3: 1421–1437.

Vilà, M., C. Basnou, P. Pyšek, et al. 2010. "How Well Do We Understand the Impacts of Alien Species on Ecosystem Services? A Pan-European, Cross-Taxa Assessment." *Frontiers in Ecology and the Environment* 8, no. 3: 135–144.

Von, S. O. 2000. "Endemism and Important Areas for Representing European Biodiversity: A Preliminary Exploration of Atlas Data for Plants and Terrestrial Vertebrates." *Belgian Journal of Entomology* 2: 21–46.

Zamora-Marín, J., A. Ruiz-Navarro, F. Oficialdegui, et al. 2023. "A Multi-Taxa Assessment of Aquatic Non-Indigenous Species Introduced Into Iberian Freshwater and Transitional Waters." *NeoBiota* 89: 17–44.

Zamora-Marín, J. M., A. A. Herrero-Reyes, A. Ruiz-Navarro, and F. J. Oliva-Paterna. 2023. "Non-Indigenous Aquatic Fauna in Transitional Waters From the Spanish Mediterranean Coast: A Comprehensive Assessment." *Marine Pollution Bulletin* 191: 114893.

Zizka, A., D. Silvestro, T. Andermann, et al. 2019. "CoordinateCleaner: Standardized Cleaning of Occurrence Records From Biological Collection Databases." *Methods in Ecology and Evolution* 10, no. 5: 744–751.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Venn diagram plots of Spain, Portugal, Andorra, and Gibraltar. The squares represent the proportionally shared established non-native species among the countries of the Iberian Peninsula. **Figure S2:** Number of established non-native species for each taxonomic group across each political entity. Colour represents the different taxonomic groups. **Figure S3:** Sankey chart of the introduction pathways of each taxonomic group in (a) Spain, (b) Portugal, (c) Andorra, and (d) Gibraltar. The width of the flows is proportional to the number of species within each group and pathway. **Figure S4:** Annual first records of non-native species in the Iberian Peninsula are split into Spain (orange), Portugal (green), Andorra (red), and Gibraltar (blue). The trends represent a running median with a 10-year moving window. The dashed black line represents the sum of the individual trends of countries of the Iberian Peninsula (i.e., Spain, Portugal, Andorra, and Gibraltar). **Table S1:** Sources used to complete the preliminary list of established non-native species. **Table S2:** Sources used to extract the native range of each species with a brief description. **Table S3:** List of established non-native species in the Iberian Peninsula accompanied by pathways, phylum, class, family, and native range.