A peer-reviewed open-access journal
NeoBiota
Advancing research on alien species and biological invasions

NeoBiota 108: 21–52 (2026)
DOI: 10.3897/neobiota.108.175337

Data Paper

From soil to stream and sea: species richness and distribution of alien invertebrates in Romania

Cristina Preda[1], Costică Adam[2], Ioana Cristina Constantinescu[2], Oana Paula Popa[2], Luis Ovidiu Popa[2], Maxim-Jean Bâlcu[2], Andreea Maria Brezeanu[2], Maria-Magdalena Dascălu[3], Andreea-Cătălina Drăghici[2,4], Carla Flavia Gavrilescu[5], Athanasios Alexandru Gavrilidis[6], Voichița Gheoca[7], Elena Iulia Iorgu[8], Ionuț Ștefan Iorgu[8], Ana Maria Krapal[2], Sanda Maican[9], Cosmin-Ovidiu Manci[10], Nicolae Manta[11], Minodora Manu[12], Rozalia Magda Motoc[2], Iulian M. Niculae[6], Ana-Maria Petrescu[2], Alexandru-Mihai Pintilioaie[13,14], Alexandra Florina Popa[2], Ioan Alexandru Rădac[15], Laurentiu Rozylowicz[5,6], Adrian Ruicănescu[16], Tiberiu C. Sahlean[9], Victor Surugiu[17], Cecilia Șerban[18], Andrei Ștefan[2], Levente Székely[19], Ioan Tăușan[7], Marius Skolka[1]

1 Research Center of the Department of Natural Sciences, Faculty of Natural and Agricultural Sciences, Ovidius University of Constanta, Constanta, Romania
2 "Grigore Antipa" National Museum of Natural History, Bucharest, Romania
3 Integrated Center of Environmental Science Studies in the North-Eastern Region (CERNESIM), Institute of Interdisciplinary Research, "Al. I. Cuza" University of Iași, Iasi, Romania
4 Doctoral School of Biology, Faculty of Biology, University of Bucharest, Bucharest, Romania
5 Faculty of Natural and Agricultural Sciences, Ovidius University of Constanta, Constanta, Romania
6 University of Bucharest, Center for Environmental Research, Bucharest, Romania
7 Faculty of Sciences, Biology and Ecology Research Centre, "Lucian Blaga" University of Sibiu, Sibiu, Romania
8 Faculty of Medicine and Biological Sciences, Ștefan cel Mare University of Suceava, Suceava, Romania
9 Department of Taxonomy, Ecology and Nature Conservation, Institute of Biology Bucharest, Romanian Academy, Bucharest, Romania
10 "Oceanic-Club" Oceanographic Research and Marine Environment Protection Society, Constanta, Romania
11 Ministry of Environment, Water and Forests, Bucharest, Romania
12 Institute of Biology Bucharest, Romanian Academy, Department of Taxonomy, Ecology and Nature Conservation, Posada Research Stationary, Bucharest, Romania
13 ICI RECENT AIR Center, Laboratory of Interdisciplinary Research on the Marine Environment and Marine Terrestrial Atmosphere, Agigea, Romania
14 Doctoral School of Biology, Faculty of Biology, "Alexandru Ioan Cuza" University of Iași, Iasi, Romania
15 Department of Biology, Faculty of Chemistry, Biology, Geography, West University of Timișoara, Timisoara, Romania
16 Institute of Biological Research Cluj, National Institute of Research and Development for Biological Sciences, Cluj-Napoca, Romania
17 Faculty of Biology, "Alexandru Ioan Cuza" University of Iași, Iasi, Romania
18 "Dunărea de Jos" University, Galati, Romania
19 Brasov, Romania

Corresponding author: Cristina Preda (cristina.preda@univ-ovidius.ro)

OPEN ACCESS

Academic editor: Alain Roques
Received: 27 November 2025
Accepted: 18 June 2026
Published: 2 July 2026

Abstract

Biological invasions represent a major threat to global biodiversity, yet alien invertebrates remain among the most understudied taxonomic groups despite their severe ecological and socio-economic impacts. At European level, the EU Regulation 1143/2014 emphasizes the need for coordinated monitoring and management of invasive alien species, but implementation is hindered by the scarcity and fragmentation of information, particularly in Central and Eastern Europe.

To tackle these shortcomings, we compiled a comprehensive, FAIR-compliant dataset detailing alien invertebrate occurrences in Romania, using data from scientific literature (1865–2023), field surveys (2020–2022), and citizen science observations (up to 2023). This dataset encompasses 23415 records of 297 alien species, of which 212 are terrestrial (71.38%), 27 are freshwater (9.09%), and 58 are marine species (19.53%). Our results show that 170 species (57%) were recorded by only one source, whether scientific literature, fieldwork, or citizen science, while the remaining 127 species

Citation: Preda C, Adam C, Constantinescu IC, Popa OP, Popa LO, Bâlcu M-J, Brezeanu AM, Dascălu M-M, Drăghici A-C, Gavrilescu CF, Gavrilidis AA, Gheoca V, Iorgu EI, Iorgu IȘ, Krapal AM, Maican S, Manci C-O, Manta N, Manu M, Motoc RM, Niculae IM, Petrescu A-M, Pintilioaie A-M, Popa AF, Rădac IA, Rozylowicz L, Ruicănescu A, Sahlean TC, Surugiu V, Șerban C, Ștefan A, Székely L, Tăușan I, Skolka M (2026) From soil to stream and sea: species richness and distribution of alien invertebrates in Romania. NeoBiota 108: 21–52. https://doi.org/10.3897/neobiota.108.175337

(43%) were documented by two or more sources combined. Scientific literature yielded the highest number of species (241), but 119 of these were not confirmed by our recent fieldwork or citizen-science observations. Citizen scientists reported 60 alien species, eight of which were recorded solely through this approach. The dataset also emphasizes spatial clustering around major urban areas in Romania and waterways, reflecting introduction pathways and sampling bias. In terms of management priorities, three species of EU concern, i.e., *Faxonius limosus* (Rafinesque, 1817), *Procambarus virginalis* Lyko, 2017, and *Eriocheir sinensis* (H. Milne-Edwards, 1853), exhibit sparse occurrence records despite their invasive potential.

By mobilizing existing data into standardized and openly accessible formats, we promote evidence-based implementation of policies at national and international levels. Moving forward, comprehensive management of biological invasions requires enhanced coordination among researchers, citizen scientists, and policymakers, supported by interoperable information systems that facilitate rapid data flows.

Key words: Black Sea, citizen science, Danube River, Eastern Europe, freshwater, invasive, marine, terrestrial

Introduction

Biological invasions represent one of the most significant threats to global biodiversity, as alien species are responsible for population declines, habitat degradation, and local extinctions (Pyšek et al. 2020). Recent estimates indicate that alien species are responsible for over 1200 local extinctions worldwide. At the same time, projections suggest a 36% increase in the number of alien species by 2050, with arthropods, particularly insects, likely to dominate future invasions (Seebens et al. 2021; Bacher et al. 2023; Roy et al. 2024). Furthermore, the economic and environmental costs of alien invasions are significant but probably severely underestimated, with terrestrial invertebrates alone costing the global economy over $700 billion by 2020 and invasive insects accounting for 88% of the documented costs (Renault et al. 2022).

Invertebrates represent a particularly challenging group for invasion biology research due to their taxonomic diversity, cryptic life histories, and capacity for rapid population growth and dispersal (Cardoso et al. 2020). Alien invertebrates encompass terrestrial, freshwater, and marine taxa that can cause severe ecological and economic impacts through, e.g., predation, competition with native species, disease transmission, damage to crops, and deterioration of infrastructure (Roy et al. 2019). Examples include the spinycheek crayfish (*Faxonius limosus* (Rafinesque, 1817)) spreading through Danube tributaries, the brown marmorated stink bug (*Halyomorpha halys* (Stål, 1855)) causing severe agricultural damage, the Asian hornet (*Vespa velutina* Lepeletier, 1836) threatening native pollinators and apiculture, and marine species such as the veined rapa whelk (*Rapana venosa* (Valenciennes, 1846)) and the warty comb jelly (*Mnemiopsis leidyi* A. Agassiz, 1865), disrupting Black Sea ecosystems (Parvulescu et al. 2009; Haye et al. 2015; Robinet et al. 2017; Carisio et al. 2022).

Central and Eastern European (CEE) countries, including Romania, face particular challenges when tackling alien invertebrate invasions due to several converging factors that create regional vulnerability (Pyšek et al. 2012). The region serves as a historical trade hub with extensive terrestrial, freshwater, and marine transportation networks, particularly the Rhine-Danube and the corridors linking the Ponto-Caspian region to the rest of Europe, which facilitate the rapid spread of species across biogeographic and national boundaries (Bij de Vaate et al. 2002; Leuven et al. 2009; Trichkova et al. 2014). For example, 44.4% of the alien macroinvertebrates in the Rhine originate from the Ponto-Caspian region, acting as a major donor of alien freshwater animal species in Europe (Leuven et al. 2009). Furthermore, continental climate conditions create suitable environments for the establishment of many temperate invasive species, while the high proportion of agricultural landscapes makes the region especially susceptible to crop-damaging invertebrate pests (Hulme 2009). Economic transitions after the 1990s and European Union (EU) accession of CEE countries have dramatically increased trade connectivity, intensifying invasion opportunities (Pyšek et al. 2012; Anastasiu et al. 2024).

To prevent the introduction of alien species that threaten ecosystems, habitats, or native species, or to control or eradicate them as mandated by the Convention on Biological Diversity (Convention on Biological Diversity 2014), the EU has developed a comprehensive policy framework for invasive alien species. EU Regulation 1143/2014 establishes legally binding measures for the prevention, early detection, rapid eradication, and management of alien species of EU concern across Member States (Genovesi et al. 2015; Roy et al. 2019; Nunes et al. 2025). At the core of the Regulation is the list of invasive alien species of EU concern, which has expanded from 37 species in 2016 to 114 by 2025, demonstrating the dynamic nature of invasions and a growing interest in the field (European Commission 2025). The EU Biodiversity Strategy 2030 also sets ambitious targets to reduce by 50% the number of Red List species threatened by invasive alien species (European Commission 2020; Pindaru et al. 2023), in line with Target 6 of the Kunming-Montreal Global Biodiversity Framework (Convention on Biological Diversity 2022). A key management tool required by EU Regulation 1143/2014 is the national Early Detection and Rapid Response (EDRR) system, which is based on robust monitoring of alien species in Member States and supported by the European Alien Species Information Network (EASIN) (Katsanevakis et al. 2015).

Romania's research on alien species has evolved substantially, transitioning from opportunistic first records of species and studies to systematic field surveys, database development, exploring management options, and stakeholders' perceptions (Preda et al. 2012; Anastasiu et al. 2016; Preda and Groom 2021; Smith et al. 2022; Garcia-Lozano et al. 2025). A recent nationwide alien species field survey (2020–2022) culminated in comprehensive databases documenting occurrence records for 396 alien plant species and 35 alien fish species (Anastasiu et al. 2024; Dragan et al. 2024). However, research on alien invertebrates remains fragmented and is published mostly in local journals, with limited data availability in major international databases such as the Global Biodiversity Information Facility - GBIF (Groom et al. 2019, 2025a; Price-Jones et al. 2022; Roy et al. 2024). Critical data gaps persist, including limited research on marine species or invasive microorganisms and pathogens, incomplete systematic surveys of invertebrates other than specific pest species, minimal research on impacts of invasive species at local or national scale, successes or failures of management initiatives, and insufficient integration of citizen science contributions (Anastasiu et al. 2016; Cogalniceanu et al. 2020).

The absence of a comprehensive, standardized, and accessible database of alien invertebrates in Romania represents a significant obstacle to effective management of biological invasions, policy implementation, and scientific research. Such databases are essential for supporting the implementation of EU Regulation 1143/2014 (Katsanevakis et al. 2024; Groom et al. 2025b; Nunes et al. 2025). The integration of multiple data sources, such as scientific literature, systematic field surveys, and citizen science observations, provides the most comprehensive approach to documenting alien species distributions and trends, while acknowledging the inherent biases and uncertainties associated with different data types (Pocock et al. 2024).

This study aims to address critical knowledge gaps on the status of alien invertebrates in Romania and to promote further research on biological invasions. To this end, we provide (1) a comprehensive FAIR-compliant dataset of alien invertebrate species in Romania, integrating occurrence records from three sources, i.e., scientific literature (1865–2023), systematic nationwide field surveys (2020–2022), and citizen science observations (up to 2023) (Groom et al. 2017; Reyserhove et al. 2020); and (2) an assessment of the dataset in terms of data quality, reliability, and complementarity of different data sources, taxonomic and geographic gaps in knowledge, and sampling biases.

Methods

Data collection

Alien invertebrate occurrences in Romania were documented using three main sources: scientific literature published up to the end of 2023; fieldwork conducted between 2020 and 2022, and research-grade citizen science data available on iNaturalist.org up to the end of 2023. Harmful organisms listed in Regulation (EU) 2016/2031 of the European Parliament and of the Council and Commission Implementing Regulation (EU) 2019/2072 of 28 November 2019 establishing uniform conditions for the implementation of Regulation (EU) 2016/2031 were excluded from this database. We considered as alien only human-introduced species (IPBES 2023), including taxa native to other parts of Europe (e.g., Ponto-Caspian, Mediterranean) where their introduction to Romania was clearly human-mediated.

Data from the scientific literature were obtained by searching the Google Scholar database using keywords in Romanian and English (i.e., “invasive species”, “alien species”, “introduced species”, “non-native species”, “allochthonous”, “specii invazive”, “specii străine”, “specii introduse”, “specii alogene”, “specii alohtone”, and “Romania”). Literature not indexed by the Google Scholar database was retrieved by checking the papers for additional references and authors’ knowledge on specific taxa or realms. We identified 488 relevant items published between 1866 and 2023, i.e., 374 journal articles, 77 books and book chapters, 21 conference papers, and 16 theses and reports (Suppl. material 1).

Data extracted from published sources were supplemented by a nationwide intensive fieldwork campaign carried out between 2020 and 2022 (MEFW 2022). The fieldwork was also used to validate the records reported in the scientific literature. Different sampling methodologies were employed during fieldwork, specific to each realm, i.e., terrestrial, freshwater, and marine ecosystems (Popa et al. 2020, 2022, 2023; Adam et al. 2022, 2023b, 2023a; Popescu Mirceni et al. 2022, 2023; Surugiu et al. 2022).

The survey of terrestrial invertebrates was conducted in 64 quadrats of 5 × 5 km, randomly selected within priority introduction pathways, and in 166 quadrats of 10 × 10 km, randomly distributed across Romania (four quadrats per county and two quadrats in the capital’s metropolitan area). The priority introduction pathways were identified in the desk-study stage from published records and expert knowledge, and corresponded to ports and other transport hubs, urban green areas, plant nurseries, agricultural and horticultural land, and storage facilities. Additional data were collected from areas the authors considered suitable for specific taxa (i.e., convenience sampling). This stratified design ensured good spatial coverage at the national level, together with a focused effort on known hotspots of alien species. The survey was conducted by experts with knowledge of specific taxa (the authors of this paper and collaborators), who visited each randomly selected quadrat once during the optimal phenological window for the target group. Fieldwork was distributed over three sampling seasons (2020–2022) and concentrated from spring to autumn (approximately April–October), with peak effort in late spring and summer, when most taxonomic groups are most active; sampling was extended into the cold season for overwintering or year-round taxa (e.g., synanthropic Coleoptera and Blattidae in heated indoor habitats, certain Heteroptera in their overwintering shelters). Methods were taxa-specific and combined active and passive techniques: sweep-netting along linear transects (typically five 250 m transects, 10–20 m wide), beating of foliage in the shrub and tree layers, hand-collection and aspiration with pooters, pitfall, Malaise, yellow-pan, light and pheromone traps, sieving and Berlese–Tullgren extraction of leaf litter and soil, direct searches of bark, deadwood, fruit, galls and host-plant tissues, and inspection of synanthropic microhabitats (dwellings, storehouses, beehives, stored produce); aquatic stages of Culicidae were sampled from natural and artificial water-holding containers using limnological hand-nets and phytoparasitic nematodes were extracted from rhizosphere soil and plant tissues. Collected specimens were preserved in 70–96% ethanol or dry-mounted, and identified to species level in the laboratory under stereomicroscopes. A full taxon-specific sampling protocol is detailed in Adam et al. (2022).

Occurrence records for alien freshwater invertebrates were collected from the same quadrats used for the survey of terrestrial invertebrates, supplemented with convenience sampling in rivers, lakes, reservoirs, and wetlands representative of the main invasion corridors. As with terrestrial invertebrates, the methodology, exact location, and timing of the observations were taxon-specific. Species inhabiting both freshwater and terrestrial habitats were assigned to the freshwater survey. Sampling combined linear-transect and fixed-point methods, including hand dredges along defined sections, grab dredges for deeper soft substrata, visual surveys with bathyscopes in clear shallow waters, kick-sampling and sweeping of submerged vegetation with a limnological net, scraping of hard substrates for sessile fauna, baited traps for decapods, and plankton-net tows for planktonic stages and bryozoan statoblasts; sediment was washed through stacked sieves to retrieve macroinvertebrates and meiofauna. Popa et al. (2020) describe the survey methodology in detail.

Sampling of alien marine invertebrates was performed by investigating hotspots identified in the scientific literature along the Romanian coast of the Black Sea (ports, marinas, the Danube–Black Sea Canal, lagoons, and bays). Additional data were obtained from areas considered suitable for specific taxa (convenience sampling). The survey was conducted by experts with expertise in specific taxonomic groups (the authors of this paper and their collaborators), who visited each sampling area at least once. Each station was surveyed by combining SCUBA-based visual transects, dredging of soft substrata along linear transects and at fixed points, manual collection and scraping of epibiosis on hard substrata, quadrat counts for large sessile or vagile species, and plankton-net tows in the surface layer for meroplankton and zooplankton; environmental parameters (temperature, salinity) were recorded *in situ*, and biological material was sieved, fixed and preserved in the field for laboratory identification. A detailed taxa-specific sampling methodology is available in Surugiu et al. (2022).

To complement the literature data and our nationwide field surveys, we incorporated records of alien invertebrate occurrences contributed by the citizen science community. Research-grade observations reported on iNaturalist.org through the end of 2023 were retrieved from the Global Biodiversity Information Facility (GBIF), retaining only records identified to the species level and validated by the iNaturalist community of users (GBIF 2025; iNaturalist community 2025). These records covered all three realms and were particularly valuable for widespread or conspicuous taxa, as well as for filling geographic gaps not covered by the systematic field surveys.

All entries in the database were curated to comply with GBIF Darwin Core Archive (DwCA) and checked for accepted species names using GBIF Backbone Taxonomy (GBIF Secretariat 2023) and Catalogue of Life database (Bánki et al. 2025). For each entry, we filled in the fields indicated in Table 1 for the occurrence database and in Table 2 for the species checklist.

Table 1. Occurrence database structure.

Column label	Column descriptions
occurrence ID	A unique alphanumeric identifier.
accepted Name Usage	The full accepted scientific name with authorship and date information, according to Catalogue of Life (Bánki et al. 2025).
accepted Name Usage ID	Taxon id in Catalogue of Life (Bánki et al. 2025).
scientific Name	The full scientific name, with authorship and date information, according to GBIF Backbone Taxonomy (GBIF Secretariat 2023).
Kingdom	The full scientific name of the kingdom in which the dwc:Taxon is classified, according to GBIF Backbone Taxonomy (GBIF Secretariat 2023).
Phylum	The full scientific name of the phylum or division in which the dwc:Taxon is classified, according to GBIF Backbone Taxonomy (GBIF Secretariat 2023).
Class	The full scientific name of the class in which the dwc:Taxon is classified, according to GBIF Backbone Taxonomy (GBIF Secretariat 2023).
Order	The full scientific name of the order in which the dwc:Taxon is classified (GBIF Secretariat 2023).
Family	The full scientific name of the family in which the dwc:Taxon is classified.
Genus	The full scientific name of the genus in which the dwc:Taxon is classified.
recorded By	Name or username of the persons who were the primary observers (for HumanObservation or MachineObservation) or citation of document included in Suppl. material 1 if the source is published literature (MaterialCitation).
event Date	Year of record or publishing date if MaterialCitation.
basis Of Record	The specific nature of the data record: MaterialCitation if retrieved from the literature, HumanObservation if derived from our fieldwork (authors' and collaborators' observations), and MachineObservation if retrieved from GBIF/iNaturalist.org.
continent	The name of the continent in which the dcterms:municipality occurs.
country Code	ISO 3166-1-alpha-2 country code.
County	ISO 3166-2 code of the county.
municipality	Name of locality at LAU2 level (LAU – NUTS 2024), according to Eurostat, or blank if no spatial overlap with a LAU area (e.g., Black Sea).
Habitat	Realm: freshwater, terrestrial, marine.
decimal Latitude	Geographic latitude in decimal degrees, exact location if citizen science and human observation, or centroid of ETRS 10 × 10 km cell grids if published literature.
decimal Longitude	Geographic longitude in decimal degrees, exact location in case of Citizen Science and Human Observation data, or centroid of ETRS 10 × 10 km cell grids if the source was published literature.
coordinate Uncertainty In Meters	100 m if GPS data, 5000 m if data was derived from the literature without geographic coordinates but with indication of a settlement, 50000 m if data was derived from the literature without geographic coordinates and without indication of a settlement but of a region.
biogeographical Region	Name of European Biogeographical Region included in the Habitats Directive (European Topic Centre 2008).
higher Geography	Land unit name according to Posea and Badea (1984).
water Body	Name of the nearby water body if the species belongs to the aquatic realm.

Table 2. Alien species checklist database structure.

Column label	Column descriptions
species ID	A unique alphanumeric identifier.
accepted Name Usage	The full accepted scientific name with authorship and date information, according to Catalogue of Life (Bánki et al. 2025).
accepted Name Usage ID	Taxon id in Catalogue of Life (Bánki et al. 2025).
Kingdom	The full scientific name of the kingdom in which the taxon is classified, according to Catalogue of Life (Bánki et al. 2025).
Phylum	The full scientific name of the phylum or division in which the taxon is classified, according to Catalogue of Life (Bánki et al. 2025).
Class	The full scientific name of the class in which the taxon is included according to Catalogue of Life (Bánki et al. 2025).
Order	The full scientific name of the order in which the taxon is classified (Bánki et al. 2025).
Family	The full scientific name of the family in which the dwc:Taxon is classified.
Genus	The full scientific name of the genus in which the dwc:Taxon is classified.
Habitat	Realm: freshwater, terrestrial, marine.
first Record	First record in database.
last Record	Last record in database.
ias EU	TRUE, if the species is included in the List of species of Union concern in 2025 (European Commission 2025).
ias RO	TRUE, if the species is included in the provisional List of species of interest for Romania (MEFW 2022).
native Range Detailed	The native range at a continental or ocean level, with regional details if available.
native Range	The native range standardized at a continental or ocean level.
introduction Pathways	The most probable pathway of introduction in Romania, as reported in the literature included in Suppl. material 1 or in taxonomic databases; based on the categories included in the Convention on Biological Diversity (Convention on Biological Diversity 2014).
references	The main sources used to extract the information.

Data analysis

We used exploratory data analysis to examine the sources of data (literature, fieldwork, and citizen science), occurrences and species by realm, and occurrences and species accumulation by year and realm. Furthermore, for each realm, we used contingency analyses and Venn diagrams to represent the source of data by species. Additionally, alien invertebrate species were ranked by the number of records. Exploratory data analysis was performed using R 4.5.2 (R Core Team 2026) and packages dplyr (Wickham et al. 2014) for descriptive statistics, ggplot2 for occurrence and species accumulation curves (Wickham 2016), and ggvenn (Linlin 2023) for Venn diagrams.

We also mapped species occurrence records at a spatial resolution of 100 km^2 (10 × 10 km) using LAEA ETRS 89 grid cells (EPSG:3035) projection, the standard grid for reporting species distribution in the EU. Data without coordinates (e.g., occurrence records included in literature) were assigned to a single ETRS 89 grid cell based on the author's knowledge of the species' habitat requirements and the visual help of Google Earth satellite imagery (Google Earth 10.75.0.1, Google LLC). Occurrence records were mapped as the number of occurrences (as a measure of sampling effort and abundance of alien species) and species richness per 10 × 10 km grid cells. Furthermore, using Global Moran's I statistic for spatial autocorrelation, we tested if the number of occurrences per 10 × 10 km is spatially clustered ($Z > 0$) or dispersed ($Z < 0$) more than expected (Getis and Ord 2010). We also tested for regional sampling bias, using optimized Hot Spot Analysis Getis-Ord Gi* statistic available in ArcGIS Pro (ESRI 2025b). The distance threshold was set at

4 km to include the surrounding eight 10 × 10 km grid cells. The metric can identify areas where sampling effort was significantly lower (GiZScore < -1.96; i.e., coldspots of occurrences) or higher (GiZScore > 1.96; i.e., hotspots of occurrences) than expected by chance. Spatial analyses were performed using ArcGIS Pro 3.5 (ESRI 2025a).

Throughout this dataset, one occurrence is defined as one georeferenced detection of a species at a sampling unit on a given date, regardless of the number of individuals observed. For example, the records of *Corythucha arcuata* at the national scale correspond to distinct georeferenced reports, typically one per sampling station within an infested oak stand, and not to numbers of individuals nor to numbers of infested trees. This convention follows the Darwin Core occurrence concept (Wieczorek et al. 2012) and is consistent with how occurrence records are structured in the Global Biodiversity Information Facility (GBIF).

Occurrence data are included in the GBIF database (https://ipt.pensoft.net/resource?r=alieninvro, Preda et al. 2026) and the checklist of alien invertebrates as supplementary data (Suppl. material 2).

Results

Alien species richness

The current database of alien invertebrate occurrences includes 23415 records, mostly representing our observations during fieldwork (19159, 81.82%). Roughly 10% of the records in the database were extracted from the literature (2259) and 8.53% (1997 entries) from citizen scientists' observations reported by the iNaturalist community.

Most occurrences in our database are from the terrestrial realm (21115 entries, 90.18%), while records from freshwater habitats account for 1434 occurrences (6.12%) and marine observations for 866 entries (3.70%). The nationwide fieldwork performed between 2020 and 2022 contributed mostly to improved knowledge regarding the terrestrial alien invertebrates (Fig. 1A).

In terms of alien species richness, we identified 297 alien invertebrates reported from Romania (Suppl. material 2), of which 212 are terrestrial (71.38%), 27 are freshwater (9.09%), and 58 are marine species (19.53%). The earliest occurrence record dates from 1865, when Mann (1866) reported the tobacco moth *Ephestia elutella* (Hübner, 1796) from Eastern Romania, Tulcea county. The number of alien species reported from Romania started increasing in 1970 for all realms (Fig. 1B), with a sharp accumulation beginning in 2000 for terrestrial invertebrates and, to a lesser extent, for freshwater and marine invertebrates.

Out of the 297 alien invertebrate species reported from Romania (Suppl. material 2), 170 were documented only by one source (scientific literature, fieldwork, or citizen science), while a combination of sources reported 127. Scientific literature reported 241 species, of which 119 were not confirmed by our recent fieldwork or citizen scientists' observations. The citizen science data included 60 alien species, of which 8 species were detected exclusively using this approach. During the three years of fieldwork, we detected 166 alien invertebrate species, of which 43 were not previously reported in the literature or by citizen scientists. A detailed analysis of reported species by source and realm is presented in Fig. 2.

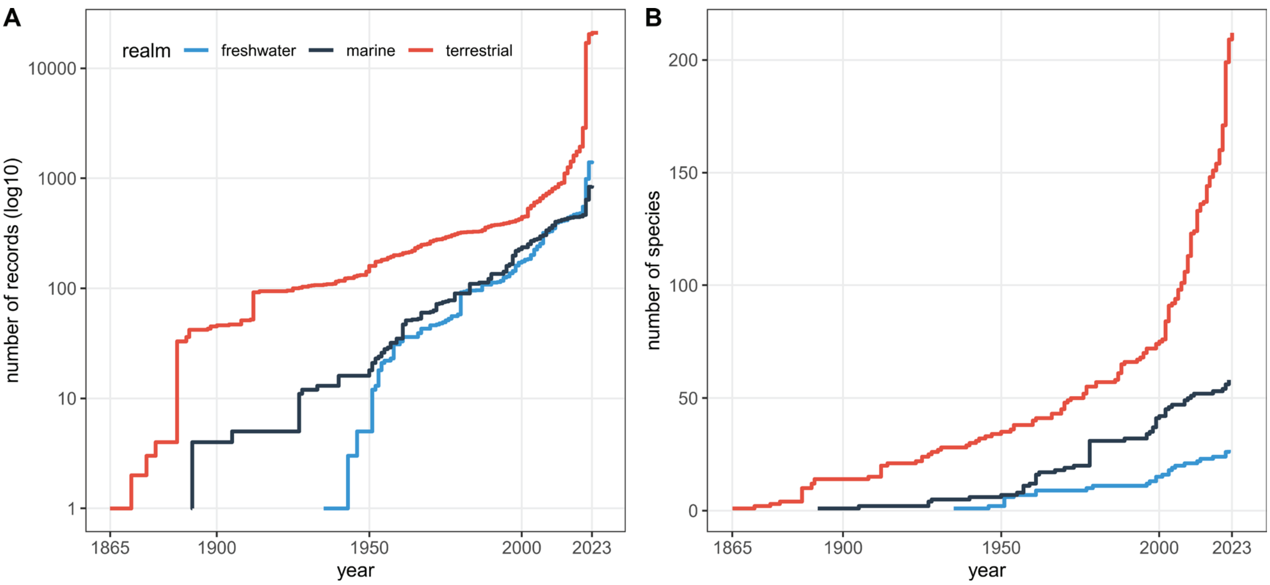

Figure 1. Number of alien invertebrate occurrence records reported from Romania between 1865 and 2023 by realm (**A**) and accumulation of new alien species by realm (**B**).

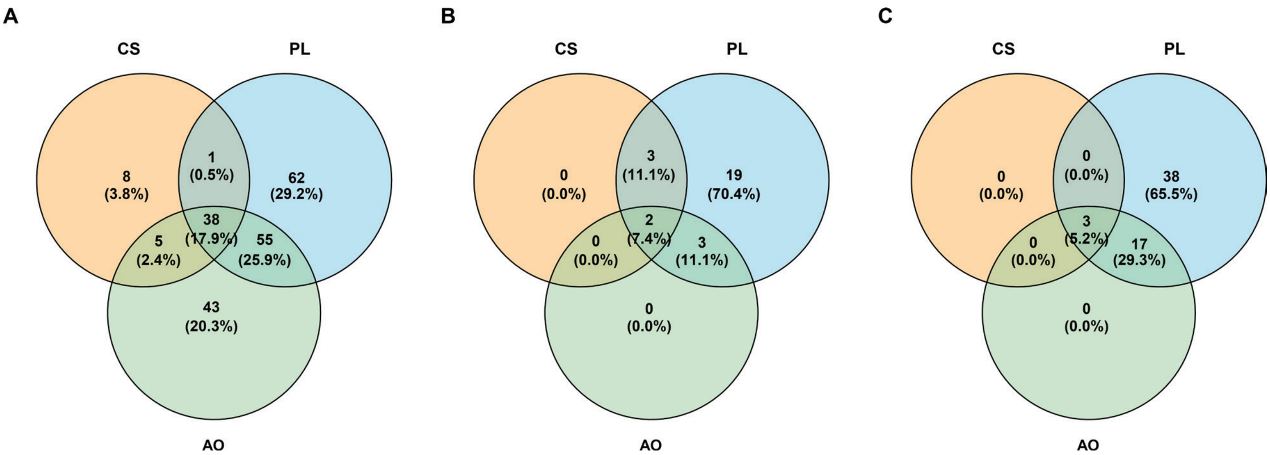

Figure 2. Number of alien species by data source: CS = citizen science, PL = published literature, AO = observations made by the authors and collaborators. **A.** Terrestrial alien invertebrates; **B.** Freshwater alien invertebrates; **C.** Marine alien invertebrates.

In the terrestrial realm, insects are the most documented group, specifically hemipterans like aphids, scale insects and leafhoppers, represented by 39 species in the database (i.e., Aphididae - 17 species, Diaspididae - 8 species, Cicadellidae - 7 species, and Coccidae - 7 species), lepidopterans like leaf miners and pyralid moths, represented by 16 species (Gracillariidae - 8 species, Pyralidae - 8 species), leaf beetles (Chrysomelidae - 9 species), wasps and ants (Eurytomidae, Sphecidae, and Formicidae - 3 species each). For the aquatic realms, most alien species recorded in the database for freshwater habitats are mollusks, like ramshorn snails and clams (Planorbidae – 3 species, and Cyrenidae – 2 species), and crustaceans, like copepods and barnacles, in marine ecosystems (Paracalanidae – 5 species, Oithonidae – 3 species, Monstrillidae – 3 species, Balanidae – 3 species). The complete list of species included in the database is provided in Suppl. material 2. A selection of the top 10 species based on the number of occurrences in each realm is presented in Table 3.

Table 3. Top 10 alien invertebrate species reported from Romania by number of occurrences and realm.

Class: Order: species	Number of records	Percentage of records in the respective realm	Year of first record
Terrestrial species			
Arachnida: Trombidiformes: *Aceria erinea* (Nalepa, 1891)	2185	10.35	1940
Insecta: Coleoptera: *Harmonia axyridis* (Pallas, 1773)	1866	8.84	2001
Insecta: Diptera: *Obolodiplosis robiniae* (Haldeman, 1847)	1255	5.94	2007
Insecta: Lepidoptera: *Parectopa robiniella* Clemens, 1863	1231	5.83	1988
Insecta: Hemiptera: *Panaphis juglandis* (Goeze, 1778)	1053	4.99	2002
Insecta: Hemiptera: *Halyomorpha halys* (Stål, 1855)	950	4.50	2002
Insecta: Hemiptera: *Corythucha arcuata* (Say, 1832)	934	4.42	2015
Insecta: Hemiptera: *Nezara viridula* (Linnaeus, 1758)	756	3.58	2010
Insecta: Lepidoptera: *Macrosaccus robiniella* (Clemens, 1859)	711	3.37	1912
Insecta: Hemiptera: *Metcalfa pruinosa* (Say, 1830)	696	3.3	2009
Freshwater species			
Bivalvia: Myida: *Dreissena bugensis* Andrusov, 1897	817	56.97	2004
Malacostraca: Decapoda: *Faxonius limosus* (Rafinesque, 1817)	159	11.09	2008
Bivalvia: Unionida: *Sinanodonta woodiana* (I. Lea, 1834)	119	8.3	1979
Bivalvia: Venerida: *Corbicula fluminea* (O. F. Müller, 1774)	112	7.81	1997
Gastropoda: Pulmonata: *Physella acuta* (Draparnaud, 1805)	61	4.25	1961
Polychaeta: Terebellida: *Hypania invalida* (Grube, 1860)	53	3.70	1935
Gastropoda: Pulmonata: *Ferrissia californica* (Rowell, 1863)	19	1.32	1946
Monogenea: Dactylogyridea: *Onchocleidus similis* Mueller, 1936	11	0.77	1951
Malacostraca: Decapoda: *Macrobrachium nipponense* (De Haan, 1849)	10	0.70	2021
Rhabditophora: Tricladida: *Girardia tigrina* (Girard, 1850)	10	0.70	1977
Marine species			
Gastropoda: Neogastropoda: *Rapana venosa* (Valenciennes, 1846)	113	13.05	1973
Polychaeta: Spionida: *Polydora cornuta* Bosc, 1802	95	10.97	1955
Bivalvia: Myida: *Mya arenaria* Linnaeus, 1758	90	10.39	1967
Hexanauplia: Balanomorpha: *Amphibalanus improvisus* (Darwin, 1854)	83	9.58	1927
Bivalvia: Arcida: *Anadara kagoshimensis* (Tokunaga, 1906)	81	9.35	1998
Tentaculata: Lobata: *Mnemiopsis leidyi* A. Agassiz, 1865	69	7.97	1989
Malacostraca: Decapoda: *Rhithropanopeus harrisii* (Gould, 1841)	64	7.39	1950
Nuda: Beroida: *Beroe ovata* (Bruguière, 1789)	44	5.08	1998
Polychaeta: Sabellida: *Ficopomatus enigmaticus* (Fauvel, 1923)	36	4.16	1962
Polychaeta: Spionida: *Dipolydora quadrilobata* (Jacobi, 1883)	18	2.08	2003

Only three of the species in the database are currently included on the List of Union concern according to the EU Regulation 1143/2014, i.e., the spinycheek crayfish *Faxonius limosus* (Rafinesque, 1817), the Chinese mitten crab *Eriocheir sinensis* (H. Milne-Edwards, 1853), and the marbled crayfish *Procambarus virginalis* Lyko, 2017. Additionally, five species of invertebrates were proposed by the Romanian Ministry of Environment (internal report) as alien species of interest for Romania: the Varroa mite, *Varroa destructor* (Anderson & Trueman, 2000), the Spanish slug, *Arion vulgaris* (Moquin-Tandon, 1855), the Chinese pond mussel, *Sinanodonta woodiana* (I. Lea, 1834), the tiger mosquito, *Aedes albopictus* (Skuse, 1894), and the blue crab, *Callinectes sapidus* (Rathbun, 1896).

The spinycheek crayfish, *F. limosus*, has been recorded 159 times at the national level, the Chinese mitten crab, *E. sinensis*, 7 times, and the marbled crayfish, *P. virginalis*, only once. The reports for the species of national concern are also scarce, i.e., 212 reports for *V. destructor*, 184 reports for *A. vulgaris*, 119 reports for *S. woodiana*, 122 reports for *A. albopictus*, and only four reports for *C. sapidus*.

When considering native ranges and pathways of introduction of alien invertebrates in the terrestrial realm, roughly half of the species originate from Asia and North America, 34.91% and 24.06%, respectively. Other regions of interest for terrestrial invertebrates include Africa (11.32%) and other parts of Europe (12.26%), and to a lesser extent Central America, South America or Australia. For 9.43% of the terrestrial species in the database, the native range is uncertain (cryptogenic). Taxa are most commonly introduced as contaminants of various commodities (56.60%) and as stowaways (31.13%). Other pathways of introduction, such as release in nature, escapes from confinement, or unaided, have been less documented. For freshwater alien species, two major donor regions are North America (48.15% of native ranges) and Asia (37.04%), followed by Europe (11.11%). Only one of the species recorded, the New Zealand mud snail, *Potamopyrgus antipodarum* (Gray, 1843), is native to New Zealand, as its common name suggests. Most introductions of freshwater alien species seem to be unintentional, either as stowaways (37.04%) or spreading using interconnected waterways (Spread: Corridor - 22.22%). Other important pathways include contaminants of various transports (14.81%) and releases in nature (14.81%), and to a lesser degree, documented escapes from confinement (3.7%). Marine alien species originate mostly from the Atlantic Ocean (56.90%) and the Pacific Ocean (25.86%), and less from the Indian Ocean (3.45%). The vast majority of species were likely introduced as a result of maritime shipping, as stowaways (Vector: Transport-Stowaway - 87.93%). In comparison, contaminants of various commodities account for only 6.9%. The relationship between native ranges and main pathways of introduction for each realm is shown in Fig. 3.

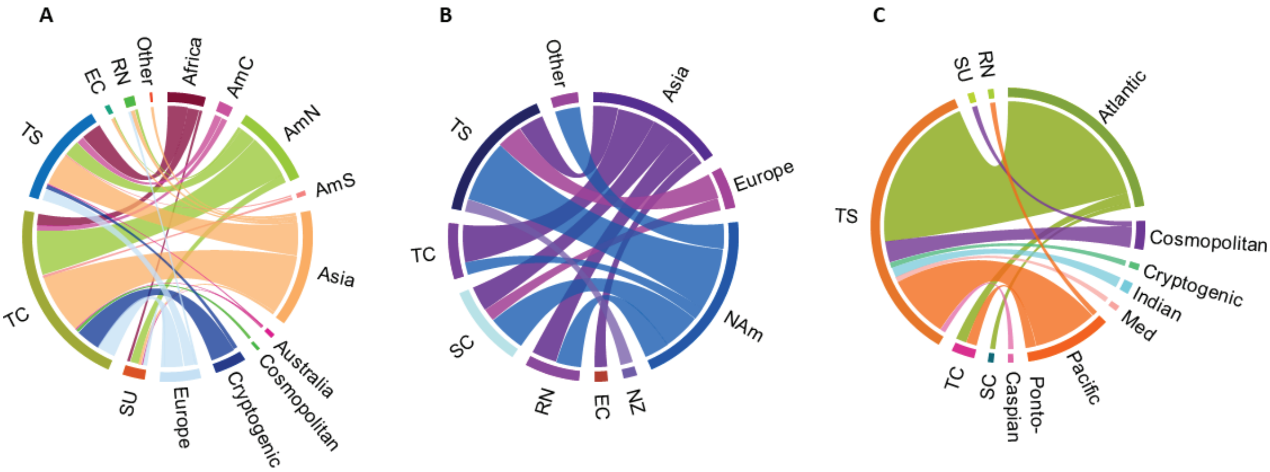

Figure 3. The number of alien species by introduction pathways and native geographical region using a chord diagram in terrestrial (**A**), freshwater (**B**), and marine (**C**) realms. Abbreviations denote: EC = Commodity: Escape from confinement; TC = Commodity: Transport-Contaminant; SC = Spread: Corridor; SU = Spread: Unaided; TS = Vector: Transport-Stowaway; RN = Commodity: Release in nature; AmS = South America; Med = Mediterranean region; AmC = Central America; NZ = New Zealand; Pacific = Pacific Ocean; Atlantic = Atlantic Ocean; Indian = Indian Ocean.

Alien species distribution

Reported occurrences of alien terrestrial invertebrate species are strongly clustered (Global Moran's I test = 0.34, Z = 17.86, $p < 0.001$) (Fig. 4A). The number of occurrences per cell varies between 0 and 701, with a few areas classified as hotspots by using Getis-Ord Gi* spatial statistic, i.e., Bucharest, Vaslui, Iasi, Galati, Constanta, Craiova, Cluj-Napoca, Timisoara and Sibiu (Fig. 4B). Alien species richness per grid cells overlapped hotspots of occurrences, with the highest richness observed in three regions of Romania, i.e., surroundings of Bucharest (Southern Romania), Cluj-Napoca (Western Romania) and Vaslui (Eastern Romania) (Fig. 4C).

Freshwater alien species occurrence records show the same clustered pattern as in the case of terrestrial species (Global Moran's I test = 0.15, Z = 9.63, $p < 0.001$). The number of occurrences per 10 × 10 km ETRS grid cell varies between 0 and 143, with the highest number recorded along the Danube river near Braila (Eastern Romania) and Orsova (Southwestern Romania), and near Oradea in the Northwestern part of Romania (Fig. 5A). Getis-Ord Gi* spatial statistic analysis indicates hotspots of occurrences along the Danube river, at Iron Gates Natural Park, Calarasi-Galati area, Giurgiu, and Danube Delta. Other hotspots were identified near Oradea in the Northwestern part of Romania, and near Comana Natural Park, close to Bucharest (Southern Romania) (Fig. 5B). When analyzing species richness, the highest number of species was recorded near Orsova on the Danube River and Sfantu Gheorghe in the Danube Delta (Fig. 5C).

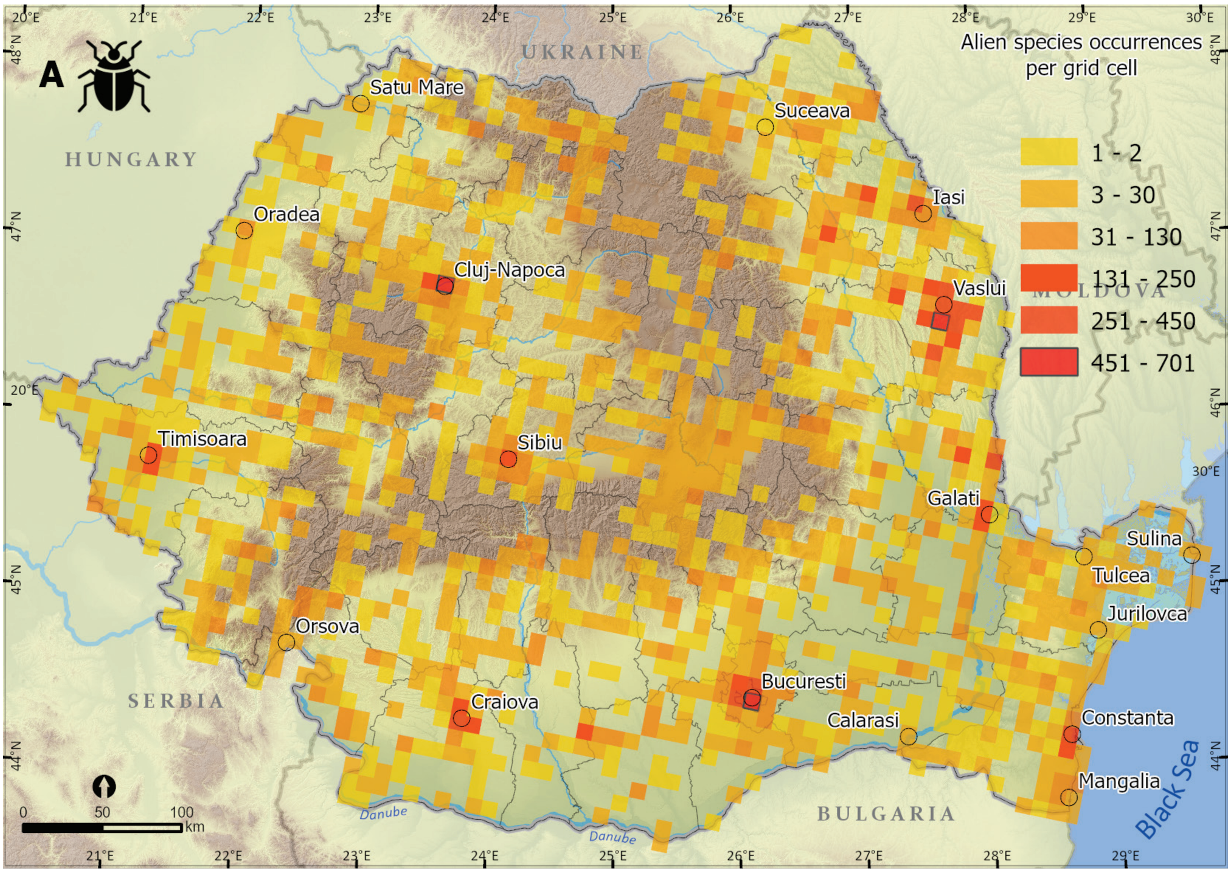

Figure 4. Spatial distribution of alien terrestrial invertebrates in Romania at 10 × 10 km grid cell resolution. **A.** Alien records per grid cell; **B.** Hotspots of occurrence records; **C.** Alien species richness per grid cell.

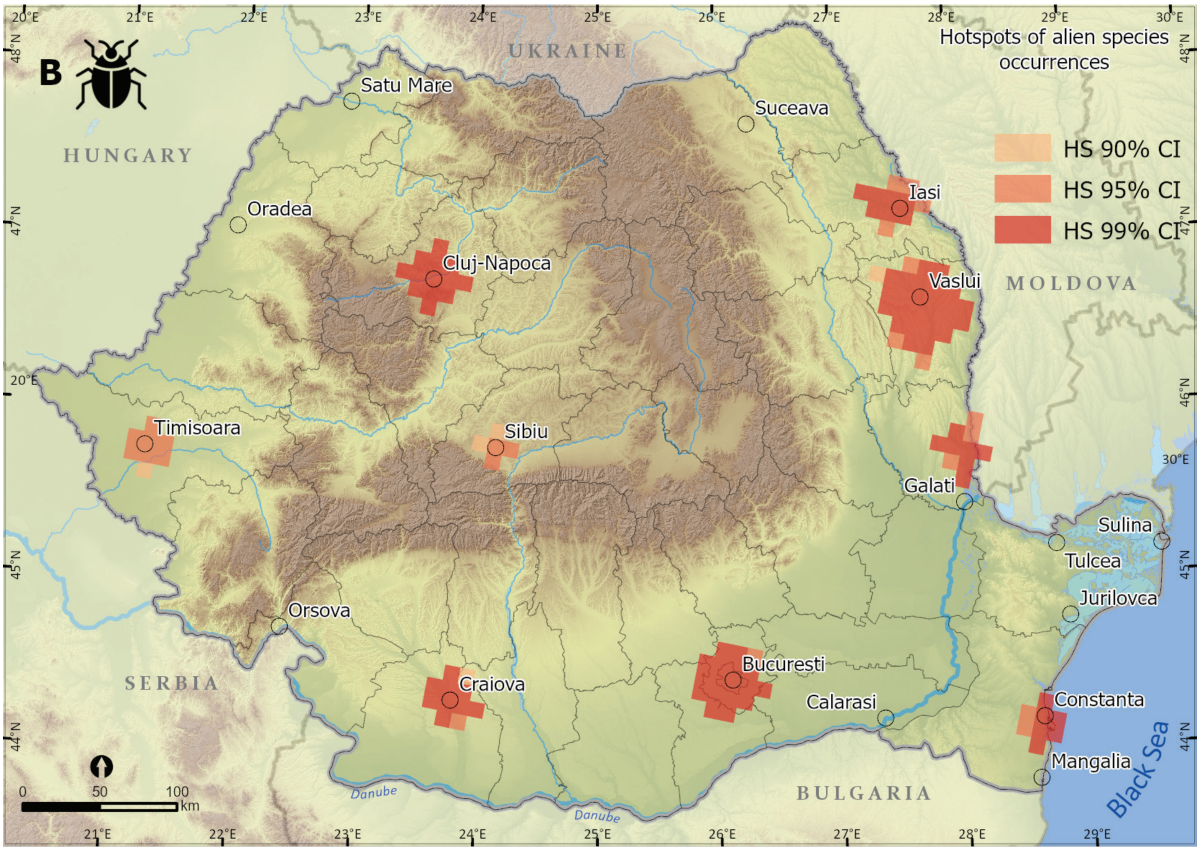

Figure 4. Continued.

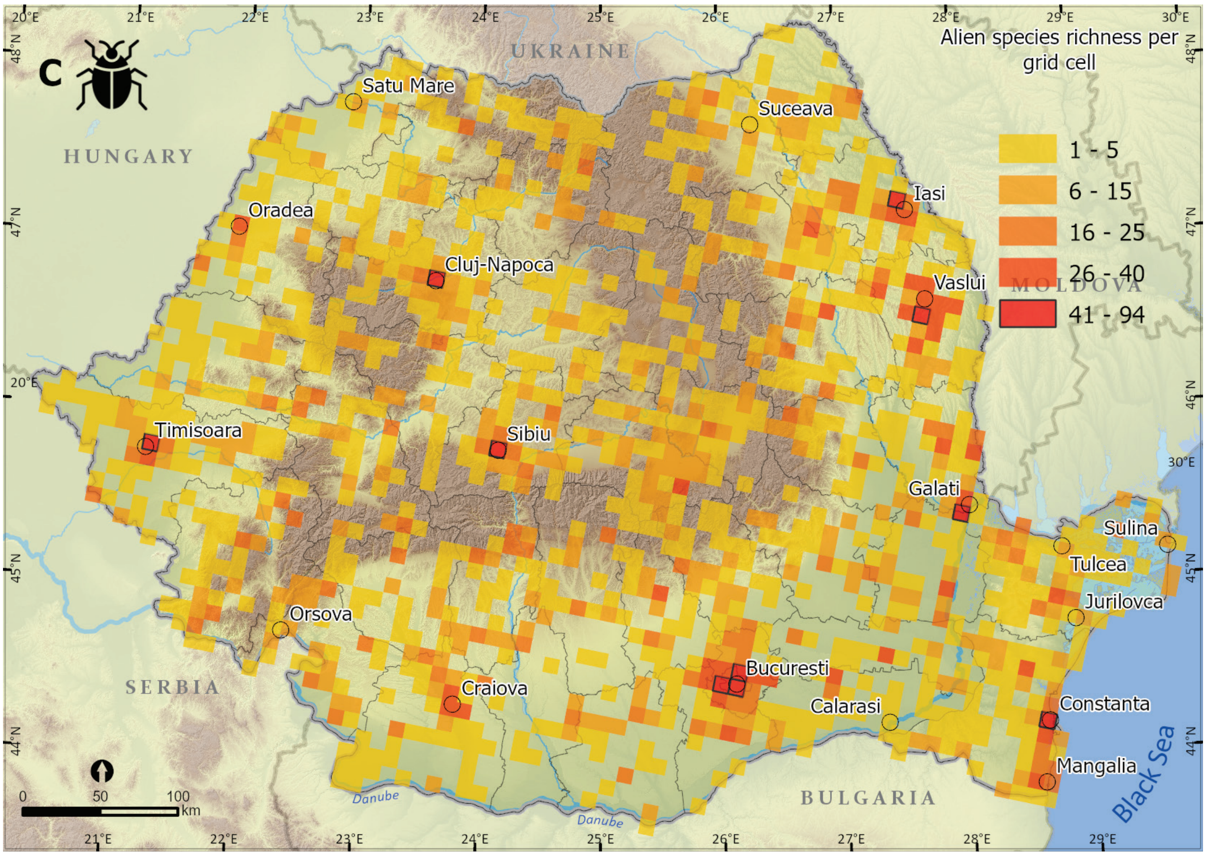

Figure 4. Continued.

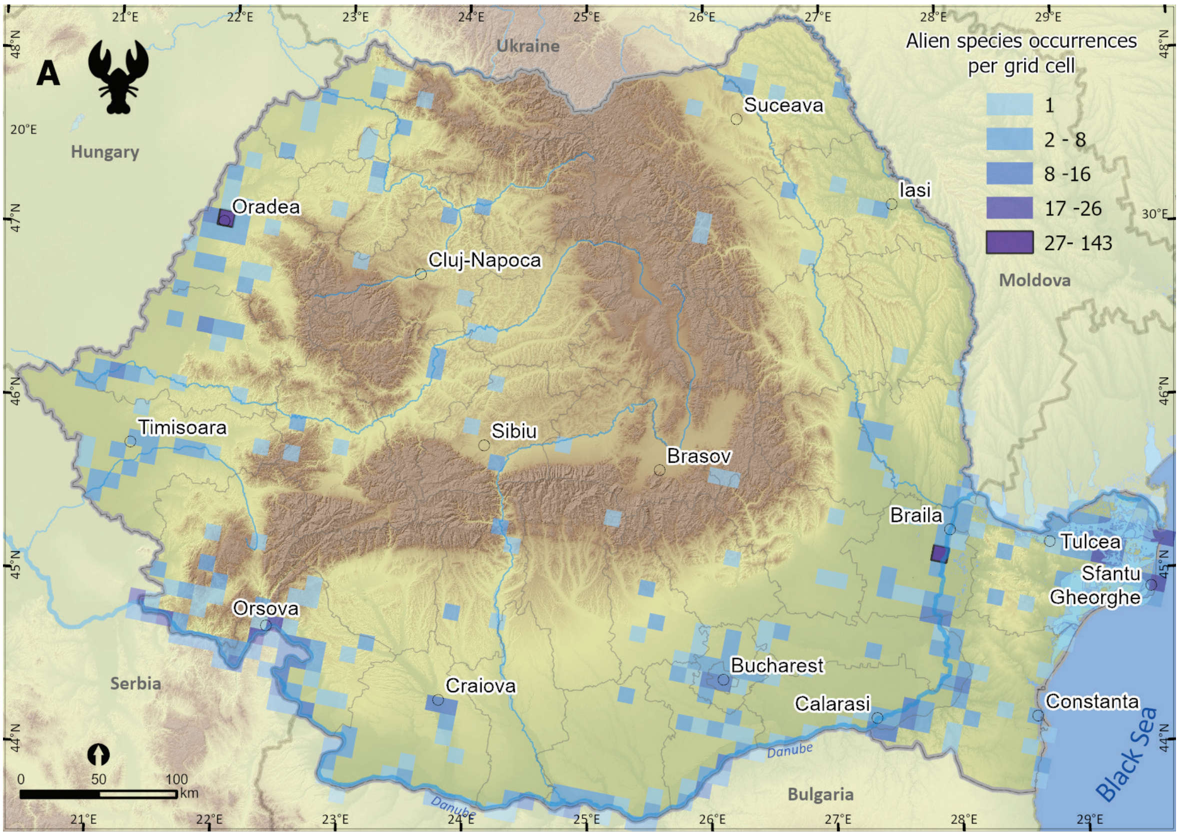

Figure 5. Spatial distribution of alien freshwater invertebrates in Romania at 10 × 10 km grid cell resolution. **A.** Alien records per grid cell; **B.** Hotspots of occurrence records; **C.** Alien species richness per grid cell.

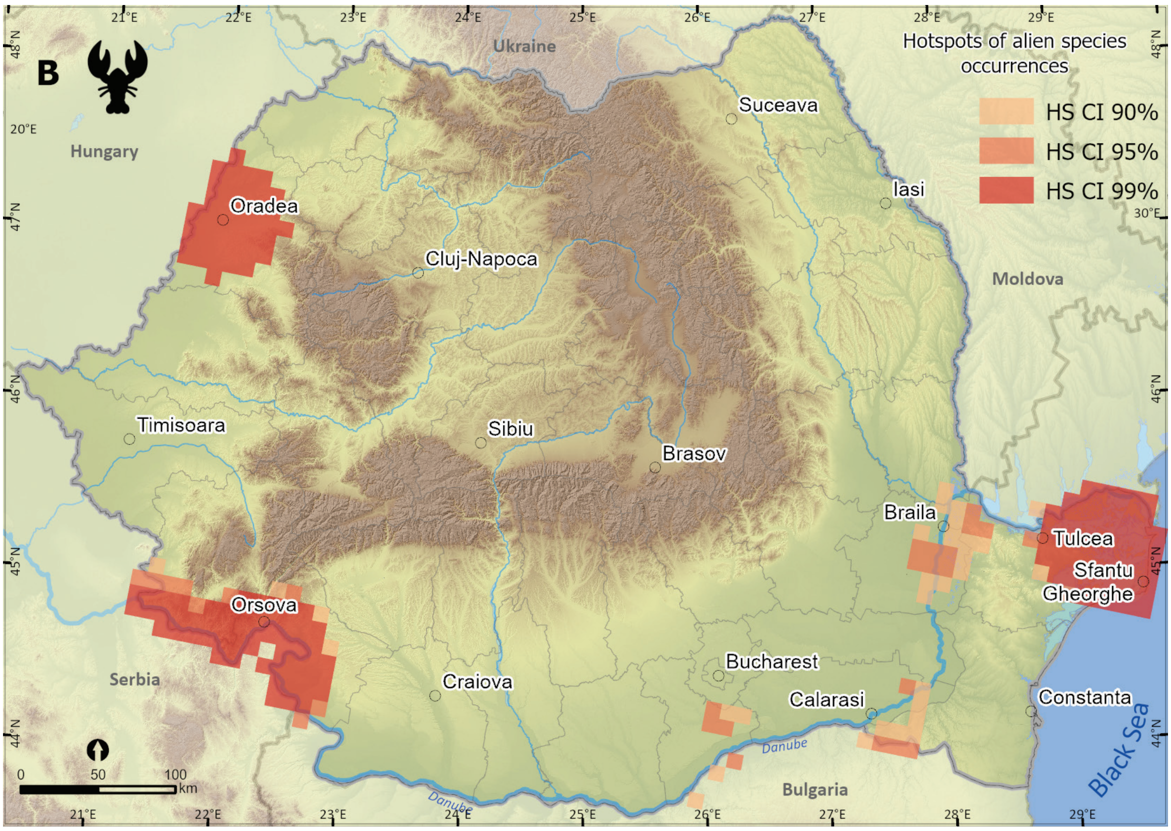

Figure 5. Continued.

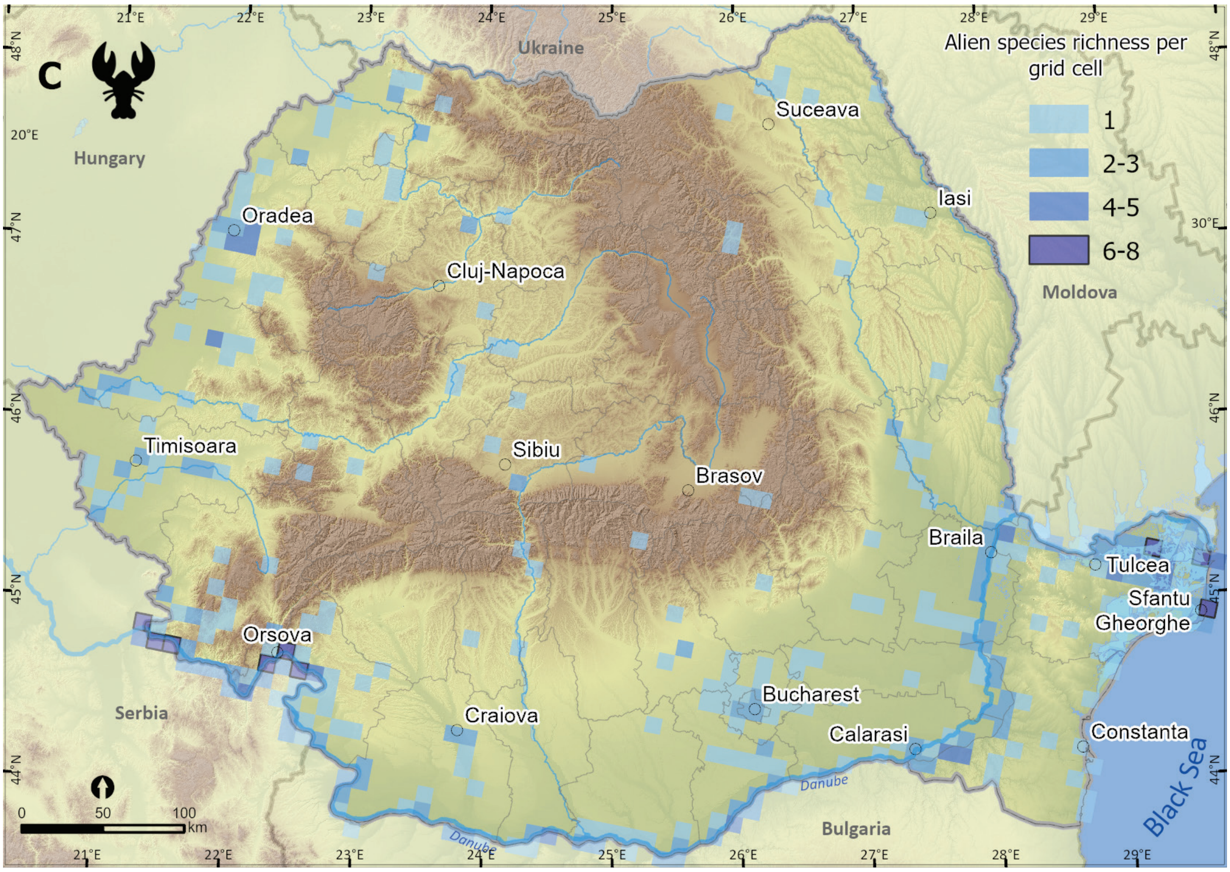

Figure 5. Continued.

Marine alien species occurrence records are also distributed in clusters (Global Moran's I test = 0.61, Z = 37.43, $p < 0.001$). The number of occurrences per 10 × 10 km ETRS grid cells varies between 0 and 118, with the highest numbers recorded near Constanta, in the southeastern part of Romania (Fig. 6A). Getis-Ord Gi* spatial statistic analysis indicates hotspots of occurrences on the northern part of the Romanian Black Sea coast, south of Gura Portitei in the Danube Delta at the interface between the Danube Delta and the Black Sea (Fig. 6B). When analyzing species richness, the highest number of species is found near Constanta and Mangalia harbors (Fig. 6C).

Discussion

Our current database contains records of 297 species of alien invertebrates, which is approximately 30% fewer than the number of alien invertebrate species previously reported in a national overview nearly a decade ago (Anastasiu et al. 2016). This apparent decline, however, rather than reflecting effective management measures applied at the national level or containment strategies, is largely artificial and is the net result of two opposing trends: (i) increased accessibility of occurrence data, which has indeed added newly arrived and previously overlooked species, offset by (ii) stricter taxonomic curation, harmonized definitions of 'alien' (*sensu* Latombe et al. 2017; Essl et al. 2018), and the removal of unverifiable historical records. Ground-truthing and consolidation of disparate records have also contributed to a more conservative estimate, in line with international calls for harmonized species reporting (Latombe et al. 2017; Essl et al. 2018; Bacher et al. 2025).

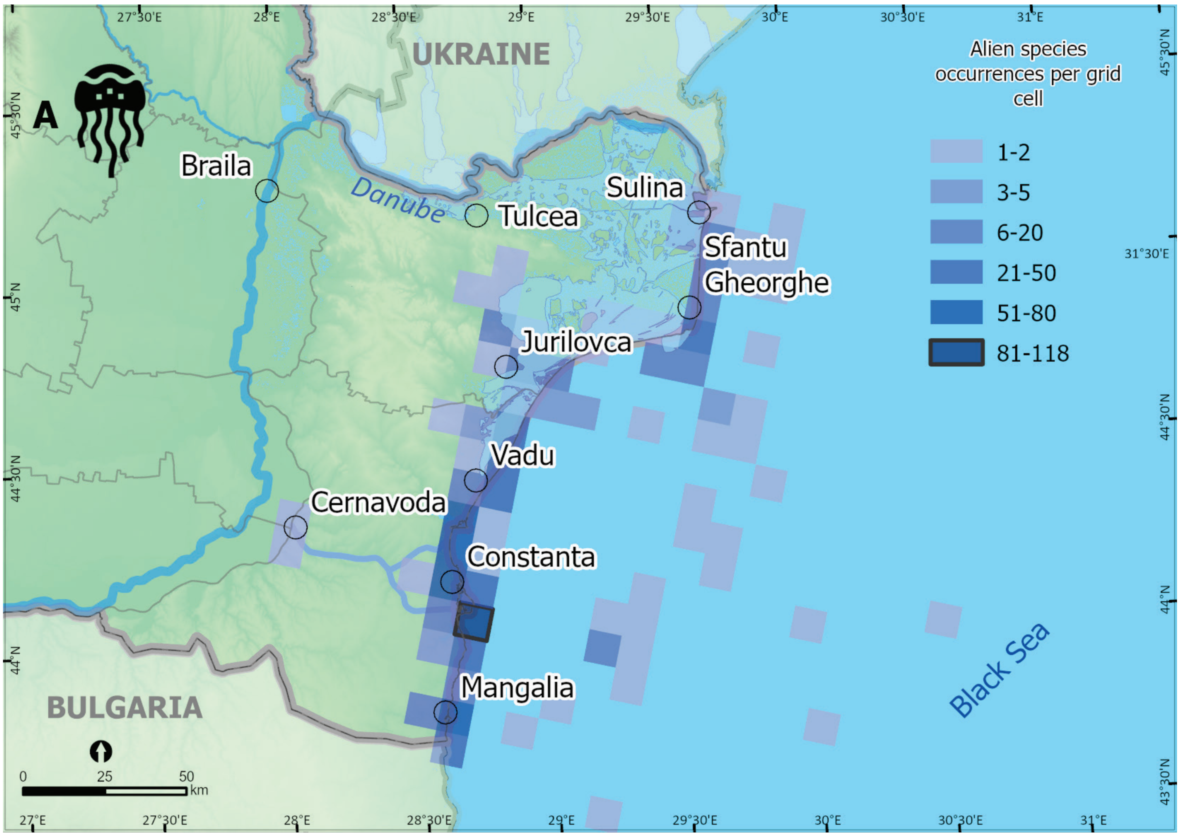

Figure 6. Spatial distribution of alien marine invertebrates in Romania at 10 × 10 km grid cell resolution. **A.** Alien records per grid cell; **B.** Hotspots of occurrence records; **C.** Alien species richness per grid cell.

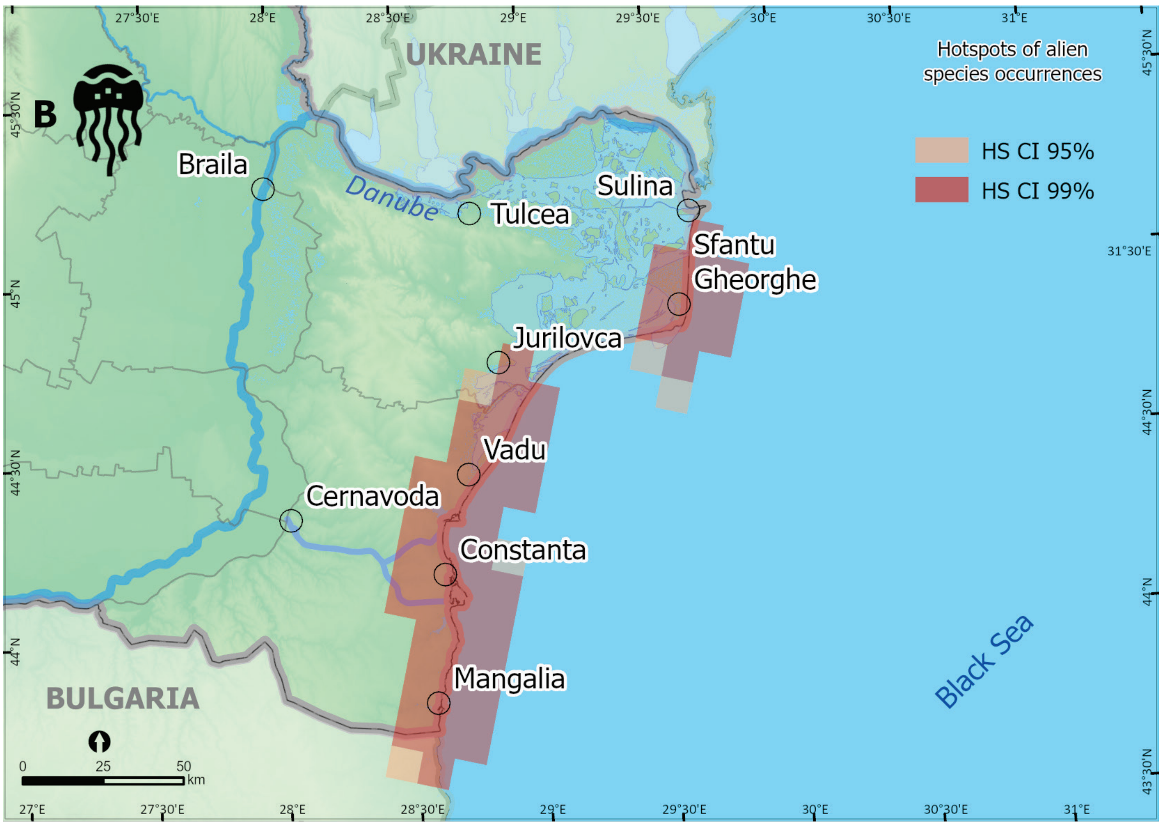

Figure 6. Continued.

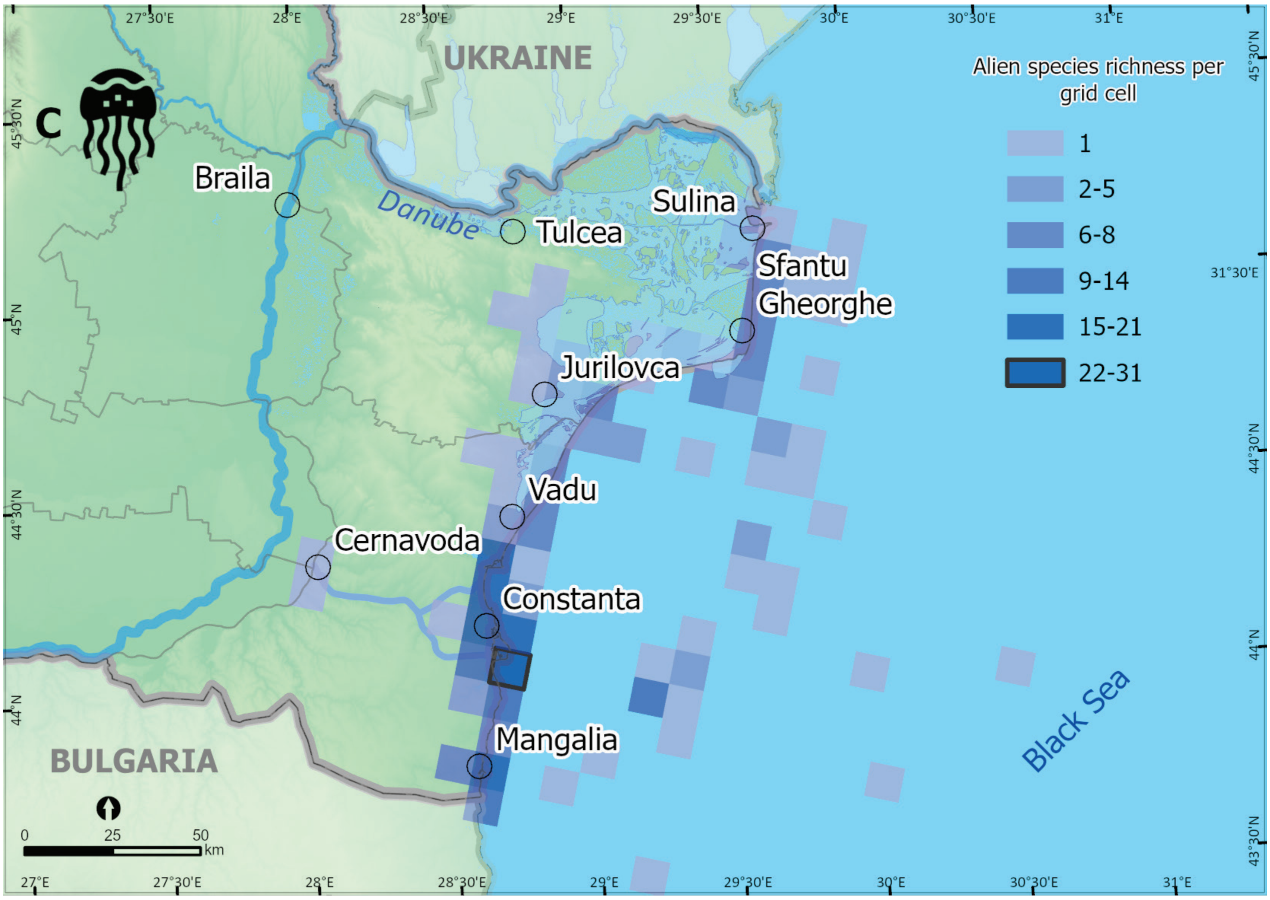

Figure 6. Continued.

The comparison of our checklist with the data available for Romania in the pan-European inventory of alien terrestrial arthropods compiled by Roques et al. (2010) revealed similar species richness (205 terrestrial arthropod species in the present study vs. 200 in Roques et al. 2010), and the two lists overlapped in approximately half of the cases. The remaining differences are attributable to three main factors. First, some species were excluded from our checklist because we did not consider taxa regulated under Regulations (EU) 2016/2031 and 2019/2072 (e.g., *Chaetosiphon* (*Pentatrichopus*) *fragaefolii* (Cockerell, 1901), *Eriosoma lanigerum* (Hausmann, 1802)). Second, several species were considered native to Romania and were therefore not included (e.g., *Caloptilia roscipennella* (Hübner, 1796), *Trichogramma brassicae* Bezdenko, 1968). Taxa native to other parts of Europe were retained as alien when their arrival in Romania was clearly human-mediated (e.g., species of Mediterranean origin), in line with current definitions of alien species (IPBES 2023). Third, the presence in Romania of several species could not be verified from the available records (e.g., *Saissetia oleae* (Olivier, 1791) (Coccidae), *Rhopalosiphoninus latysiphon* (Davidson, 1912) (Aphididae), and *Psyllipsocus ramburii* Selys-Longchamps, 1872 (Psocidae)); these taxa are listed in Suppl. material 3 and remain to be confirmed. In addition, Suppl. material 3 includes a further 37 taxa reported as present in Romania in other published sources but for which no supporting information or locality data could be retrieved; we encourage researchers to investigate these records in future studies.

The temporal trajectory of alien invertebrate introductions in Romania shows a pattern consistent with broader European and global trends. The earliest documented alien invertebrate in our database, the tobacco moth *Ephestia elutella*, was reported from Tulcea county in 1865 (Mann 1866). For more than a century, new records accumulated slowly, with only a modest increase during the second half of the 20th century. After 1970, the number of reported alien species began to rise noticeably across all realms, with a particularly sharp increase after 2000, driven largely by terrestrial invertebrates and to a lesser extent by freshwater and marine taxa. This steep growth can be partly explained by actual increases in propagule pressure linked to intensifying trade, transport, and land-use change, especially in the context of Romania's pre-accession and accession to the European Union in 2007, which facilitated the movement of goods and organisms along liberalised transport and commercial corridors (Roques et al. 2016; Seebens et al. 2017, 2021).

At the same time, the recent acceleration possibly reflects an artificial increase due to improved taxonomic expertise, increased availability of digitised museum and literature records, and the rapid growth of citizen science platforms, which have greatly enhanced species detection and reporting in the past two decades (Pocock et al. 2017, 2024; Groom et al. 2019). Similar dynamics have been observed across Europe, where more comprehensive monitoring and data mobilization efforts have contributed to sharp apparent increases in alien species richness (Latombe et al. 2017; Haubrock et al. 2023; Colling et al. 2025). Thus, the data likely reflect both real ecological processes linked to biological invasions and an expanding observation effort. The pattern for Romania remains consistent with global trajectories: biological invasions are accelerating and remain unsaturated, with invertebrates among the groups with the greatest establishment rates worldwide (Seebens et al. 2017; Bacher et al. 2023). Approximately 82% of the occurrence records in our database originate from fieldwork, performed primarily in terrestrial habitats. As expected, the marine habitats remain the least systematically surveyed, reflecting both logistical constraints and taxonomic challenges. Invertebrates are notoriously difficult to monitor and identify, often requiring specialized taxonomic expertise, sustained research efforts, and substantial financial resources (McGeoch et al. 2012; Seebens et al. 2020). Nevertheless, recent years have seen increasingly valuable contributions from citizen scientists, particularly within urban and surrounding areas (Pocock et al. 2024). In our dataset, 2.7% of alien species were documented exclusively through citizen science initiatives, underscoring the growing relevance of this participatory approach. These efforts could be further amplified through thematic events such as BioBlitzes, organized locally or as part of larger initiatives like the City Nature Challenge, which offer opportunities to raise awareness, engage non-specialist observers, and enhance early detection capacity (Pocock et al. 2017; Groom et al. 2019). Our results show that 170 species (57%) were recorded by only one source, whether scientific literature, fieldwork, or citizen science, while the remaining 127 species (43%) were documented by two or more sources combined. Scientific literature yielded the highest number of species (241), but 119 of these were not confirmed by our recent fieldwork or citizen-science observations.

Alien invertebrates represent the second most diverse group of alien species in Romania, after vascular plants (Cogalniceanu et al. 2020; Anastasiu et al. 2024). Among these, insects, mollusks and crustaceans account for the largest numbers, consistent with European trends (Roques et al. 2009; Ragkousis et al. 2023). Three alien invertebrates included on the List of Invasive Alien Species of Union concern are established in Romania, i.e., *Faxonius limosus* (Rafinesque, 1817), *Procambarus virginalis* Lyko, 2017, and *Eriocheir sinensis* (H. Milne-Edwards, 1853). Fortunately, despite recent amendments to the list (European Commission 2025), the number of Union concern species present in Romania has not increased. However, we should mention the reporting of a land planarian in western Romania in 2023 through one of the citizen science platforms (Lorincz 2024) that was later identified by platform users as *Obama nungara* Carbayo, Alvarez-Presas, Jones & Riutort, 2016, one of the species added to the List of invasive alien species of Union concern in 2025. To our knowledge, this record currently relies on a single observation without a collected specimen, requiring further investigations. Nevertheless, the example illustrates the growing importance of citizen science in the early detection of emerging invasive species. Similar contributions have proven valuable for documenting first occurrences, extending distribution ranges, and providing large-scale spatiotemporal data (Pocock et al. 2024). At the same time, such cases highlight the need for careful validation and integration of citizen-science data with expert taxonomic assessments and physical vouchers, ensuring scientific accuracy and management relevance. Strengthening collaborations between researchers, institutions, and citizen science platforms could improve both the reliability of records and the responsiveness of national monitoring schemes. This should serve as a reminder that the risk of introduction is always high and that urgent measures are needed to strengthen early warning systems and cross-border data sharing (Groom et al. 2017, 2019; Price-Jones et al. 2022).

One of the three species of Union concern established in Romania, the spiny-cheek crayfish, *Faxonius limosus*, native to North America, was first recorded in Romania in the early 2000s in the lower Danube River basin (Parvulescu et al. 2009; Schrimpf et al. 2013). Since then, the species has expanded its range into connected waterways, including tributaries and canals (Popa et al. 2020). *F. limosus* is a vector for the crayfish plague, *Aphanomyces astaci*, which poses a severe threat to native European crayfish such as the idle crayfish, *Austropotamobius bihariensis*, a species endemic to Apuseni Mountains in the western part of Romania, or *Astacus astacus*, already in decline across Europe due to habitat loss and pollution (Parvulescu 2019, Mojžišová et al. 2022; Roessink et al. 2022).

The Chinese mitten crab, *Eriocheir sinensis*, rapidly established and subsequently spread throughout much of Europe following its accidental introduction into Germany in 1912 from its native range in eastern Asia (Herborg et al. 2003). In Romania, the species was first reported in the late 1990s (Gomoiu and Skolka 1998) and later confirmed from the Danube Delta (Oţel 2004; Micu and Micu 2006). It is likely distributed along the entire lower sector of the Danube, consistent with records from neighbouring Serbia (Škraba et al. 2013) and Bulgaria (Trichkova et al. 2017). As a catadromous species, adults migrate downstream to brackish and marine waters to reproduce, while juveniles disperse upstream into freshwater habitats, capable of traveling hundreds of kilometers (Herborg et al. 2003). The species is omnivorous and exerts multiple ecological impacts. Competition and predation on benthic invertebrates, along with burrowing activity, can alter community composition and sediment dynamics, as well as contribute to riverbank erosion (Rudnick and Resh 2005; Hänfling et al. 2011). Migratory behaviour also redistributes biomass across ecosystem boundaries, potentially influencing nutrient fluxes (Rudnick and Resh 2005). *E. sinensis* has been identified as a carrier of the crayfish plague pathogen *Aphanomyces astaci*, raising additional concerns for native crayfish populations (Schrimpf et al. 2014, 2017).

The marbled crayfish, *Procambarus virginalis,* has emerged as a prominent invasive freshwater taxon in Europe, and its presence has been confirmed in northwestern Romania, where established individuals were first documented from semi-natural ponds near Oradea city (Parvulescu et al. 2017). Its ability to reproduce from a single individual, coupled with rapid growth, high fecundity, and broad ecological tolerance, underpins its exceptional colonisation potential and explains the frequent, multi-site introductions associated with the aquarium trade (Maiakovska et al. 2021). Across invaded regions, *P. virginalis* has demonstrated strong ecological impacts: it can reach high population densities, alter benthic invertebrate assemblages, compete with native crayfish and other macroinvertebrates, and modify nutrient and sediment dynamics in small water bodies (Andriantsoa et al. 2019; Soto et al. 2024). From a biosecurity perspective, the marbled crayfish poses a high invasion risk due to its clonal reproduction and widespread availability in the pet trade, prompting regulatory responses in multiple jurisdictions (Sánchez et al. 2024).

Together, these species highlight the increasing role of alien crustaceans in altering ecosystem processes, outcompeting native species such as *Astacus astacus* and *Austropotamobius torrentium*, and complicating conservation efforts. The co-occurrence of multiple invasive decapods with overlapping ecological niches underscores the need for integrated monitoring and management strategies across the Danube catchment and at the EU level.

Spatial analysis of alien invertebrates' occurrence in Romania reveals several hotspots of species richness in and around major urban and transport hubs such as Bucharest, Constanta, Cluj-Napoca, Iași, Sibiu, and along the Danube River. These patterns underscore the critical role of international ports and infrastructure, highways and railway networks, as introduction gateways (Hulme 2009; Memedemin et al. 2016; Latombe et al. 2017). In the case of Constanta, Romania's largest Black Sea harbor, its status as a national hotspot for alien marine and brackish-water invertebrates has been previously documented (Memedemin et al. 2016). Interestingly, many of these hotspots overlap with prominent academic and research centers, most clearly seen in the case of terrestrial invertebrate alien species, suggesting the possibility of a 'botanist effect', a sampling bias whereby more records are available in well-studied areas (Ruiz et al. 2000; Pyšek et al. 2013). While this bias is an inherent challenge in alien species distribution studies, the observed clustering likely reflects a combination of true introduction patterns and research effort. The absence of some species from our dataset should be interpreted with caution, as opportunistic data can carry well-documented taxonomic, spatial, temporal and detectability biases that can distort apparent distributions and trends (Isaac and Pocock 2015; Boakes et al. 2016; Troudet et al. 2017) and should ideally be cross-checked against structured surveys for more robust and comprehensive assessments of biodiversity (Arvidsson and Birkhofer 2026). Opportunistic records consistently over-represent conspicuous, large-bodied, common and easily identifiable species, while inconspicuous or hard-to-recognise taxa are systematically under-reported (Callaghan et al. 2021; Koch et al. 2023; Díaz-Calafat et al. 2024).

Conclusion

Despite significant progress in documenting alien invertebrates in Romania and centralizing data, there is still no comprehensive official national list of alien species. Such a list should be publicly accessible and regularly updated, ideally adhering to global biodiversity data standards to ensure agreement with FAIR principles (Reyserhove et al. 2020; Price-Jones et al. 2022; Roy et al. 2024). The list could be maintained by the Romanian Ministry of Environment, with the contribution of researchers to ensure scientific rigor, on existing platforms that provide the necessary infrastructure, such as GBIF (Robertson et al. 2014). This would reduce the current fragmentation of data systems and facilitate coordinated responses to biological invasions (Groom et al. 2017, 2025a).

Monitoring efforts in Romania are in line with EU Regulation No. 1143/2014 on the prevention and management of invasive alien species, yet management actions remain sporadic and under-resourced. Increased funding, capacity building, and integrated governance are urgently needed to improve implementation and functionality of specialized legislation, as well as harmonization between relevant legal frameworks and the mandates of different ministries (Genovesi et al. 2015).

Moving forward, research should focus on ecological and socio-economic impacts to address current knowledge gaps and the prioritization of species for management interventions, following structured approaches such as the DOSI scheme (Dispersal-Origin-Status-Impact; Haubrock et al. 2025). Proactive measures are essential for detecting emerging alien species with high invasive potential, such as *Vespa velutina.* Close monitoring and assessments of their impacts, distribution, and establishment status would support timely, early-stage management (Robinet et al. 2017; Nunes et al. 2025). Establishing long-term monitoring schemes and early detection systems, alongside pilot management projects that test eradication and control measures, will be key to strengthening Romania's capacity to address invasive alien species effectively. Mobilizing resources at national and EU levels will be essential to ensure that the suggested measures are sustainable and scalable.

Acknowledgements

We would like to thank our collaborators in POIM SMIS 120008/2019 project for collecting data during the fieldwork, particularly to Bănăduc A.M., Bănăduc D.S., Cioboiu O., Cristescu M., Cupşa D., Gavril V., Iancu L., Ilie D.M., Mitroiu M.D., Oloşuţean H., Pârvulescu L., Perju M., Petrescu I., Popescu I.E., Popescu-Mirceni R.V., Popovici O.A., Prunar F.V., Ruşti D.M., Sitar C., Stanciu C.R., Tomozii I.B., Török S.C., Urák I., Vizauer T.C., Zaharia L.G. and Zaharia R. We also thank the authors of citizen science observations included in this database. Special thanks to István Lőrincz for permission to mention his iNaturalist report of *Obama nungara*.

References

Adam C, Constantinescu IC, Draghici AC, Dascalu MM, Gheoca V, Iancu L, Iorgu IS, Irimia AG, Maican S, Manu M, Petrescu AM, Popa AF, Radac IA, Rusti DM, Sahlean CT, Szekeli L, Serban C, Tausan I, Ciubuc F, Popa AM (2022) Ghid de inventariere şi cartare a distribuţiei speciilor de nevertebrate terestre alogene din România. Zenodo. https://doi.org/10.5281/zenodo.6833153

Adam C, Constantinescu IC, Drăghici AC, Fusu L, Fusu MM, Gheoca V, Iorgu IS, Irimia AG, Maican S, Manci CO, Manu M, Mitroiu MD, Oloșutean HG, Perju M, Petrescu AM, Pintilioaie AM, Popa AM, Popescu IE, Popovici OA, Prunar FV, Radac IA, Ruicănescu A, Sahlean CT, Sitar C, Stanciu CR, Szekely L, Tăușan I, Tomozii IB, Török SC, Zaharia LG (2023a) Raport final privind distribuția speciilor de nevertebrate terestre alogene din hot-spot-uri și căile prioritare de pătrundere (an 3 cartare). Zenodo. https://doi.org/10.5281/ZENODO.8224465

Adam C, Constantinescu IC, Cristescu M, Drăghici AC, Fusu L, Fusu MM, Gheoca V, Ilie DM, Iorgu IȘ, Irimia AG, Maican S, Manci CO, Manu M, Mitroiu MD, Petrescu AM, Pintilioaie AM, Popa AF, Popescu IE, Popovici OA, Prunar FV, Rădac IA, Ruicănescu A, Ruști DM, Sahlean CT, Sitar C, Stanciu CR, Szekely L, Șerban C, Tăușan I, Tomozii IB, Török SC, Urák I, Zaharia LG (2023b) Raport final privind distribuția speciilor de nevertebrate terestre alogene rezultată din activitatea de inventariere cu efort redus (an 3 cartare). Zenodo. https://doi.org/10.5281/ZENODO.8224579

Anastasiu P, Rozylowicz L, Skolka M, Preda C, Memedemin D, Cogalniceanu D (2016) Alien Species in Romania. In: Rat M, Trichkova T, Scalera R, Tomov R, Uludag A (Eds) State of the Art of Alien Species in South-Eastern Europe. ESENIAS Scientific Reports 1. University of Novi Sad Faculty of Sciences, Novi Sad, 75–89.

Anastasiu P, Miu I, Gavrilidis AA, Preda C, Rozylowicz L, Sirbu C, Oprea A, Urziceanu M, Camen-Comanescu P, Nagoda E, Memedemin D, Barbos M, Boruz V, Cislariu A, Don I, Fagaras M, Frink JP, Georgescu IM, Haruta OI, Hurdu BI, Matis A, Milanovici S, Muncaciu S, Neacsu AG, Neblea M, Nicolin AL, Niculescu M, Oroian S, Pop OG, Radutoiu D, Samarghitan M, Simion I, Soare LC, Steiu C, Stoianov E, Strat D, Szabo A, Szatmari PM, Tanase C, Mirea M, Manta N, Sirbu IM (2024) Alien plant species distribution in Romania: a nationwide survey following the implementation of the EU Regulation on Invasive Alien Species. Biodiversity Data Journal 12. https://doi.org/10.3897/BDJ.12.e119539

Andriantsoa R, Tönges S, Panteleit J, Theissinger K, Carneiro VC, Rasamy J, Lyko F (2019) Ecological plasticity and commercial impact of invasive marbled crayfish populations in Madagascar. BMC ecology 19: 8. https://doi.org/10.1186/s12898-019-0224-1

Arvidsson F, Birkhofer K (2026) The value of public databases for our knowledge of national spider biodiversity compared to a long-term scientific monitoring project. Insect Conservation and Diversity 19: 228–239. https://doi.org/10.1111/icad.70024

Bacher S, Galil B, Nunez M, Ansong M, Cassey P, Dehnen-Schmutz K, Fayvush G, Hiremath A, Ikegami M, Martinou A, McDermott S, Preda C, Vila M, Weyl OLF, Fernandez R, Ryan-Colton E (2023) Chapter 4. Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life. IPBES Invasive Alien Species Assessment, 1–222. https://doi.org/10.5281/zenodo.7430731

Bacher S, Ryan-Colton E, Coiro M, Cassey P, Galil BS, Nuñez MA, Ansong M, Dehnen-Schmutz K, Fayvush G, Fernandez RD, Hiremath AJ, Ikegami M, Martinou AF, McDermott SM, Preda C, Vilà M, Weyl OLF, Aravind NA, Angelidou I, Athanasiou K, Atkore V, Barney JN, Blackburn TM, Brockerhoff EG, Carbutt C, Carisio L, Castro-Díez P, Céspedes V, Christopoulou A, Cisneros-Heredia DF, Cooling M, de Groot M, Demetriou J, Dickey JWE, Duboscq-Carra VG, Early R, Evans TG, Flores-Males PT, Gallardo B, Gruber M, Hui C, Jeschke JM, Joelson NZ, Khan MA, Kumschick S, Lach L, Lapin K, Lioy S, Liu C, MacMullen ZJ, Mazzitelli MA, Measey J, Mrugała-Koese AA, Musseau CL, Nahrung HF, Pepori A, Pertierra LR, Pienaar EF, Pyšek P, Rivas Torres G, Rojas Martinez HA, Rojas-Sandoval J, Ryan-Schofield NL, Sánchez RM, Santini A, Santoro D, Scalera R, Schmidt L, Shivambu TC, Sohrabi S, Tricarico E, Trillo A, van't Hof P, Volery L, Zengeya TA (2025) Global Impacts Dataset of Invasive Alien Species (GIDIAS). Scientific Data 12: 832. https://doi.org/10.1038/s41597-025-05184-5

Bánki O, Roskov Y, Döring M, Ower G, Hernández Robles DR, Plata Corredor CA, Stjernegaard Jeppesen T, Örn A, Pape T, Hobern D, Garnett S, Little H, DeWalt RE, Miller J, Orrell T, Aalbu

R, Abbott J, Aedo C, Aescht E, Alexander S, Alonso-Zarazaga MA, Alvarez B, Andrella GC, Antonietto LS, Arango C, Artois T, Atahuachi Burgos M, Atkinson S, Atwood JJ, Bagnatori Sartori ÂL, et al. (2025) Catalogue of Life. https://doi.org/10.48580/dgvbl

Bij de Vaate A, Jazdzewski K, Ketelaars HAM, Gollasch S, Van der Velde G (2002) Geographical patterns in range extension of Ponto-Caspian macroinvertebrate species in Europe. Canadian Journal of Fisheries and Aquatic Sciences 59: 1159–1174. https://doi.org/10.1139/f02-098

Boakes EH, Gliozzo G, Seymour V, Harvey M, Smith C, Roy DB, Haklay M (2016) Patterns of contribution to citizen science biodiversity projects increase understanding of volunteers' recording behaviour. Scientific Reports 6: 33051. https://doi.org/10.1038/srep33051

Callaghan CT, Poore AGB, Hofmann M, Roberts CJ, Pereira HM (2021) Large-bodied birds are over-represented in unstructured citizen science data. Scientific Reports 11: 19073. https://doi.org/10.1038/s41598-021-98584-7

Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacon C, Fartmann T, Fukushima CS, Gaigher R, Habel JC, Hallmann CA (2020) Scientists' warning to humanity on insect extinctions. Biological Conservation 242: 108426. https://doi.org/10.1016/j.biocon.2020.108426

Carisio L, Cerri J, Lioy S, Bianchi E, Bertolino S, Porporato M (2022) Impacts of the invasive hornet *Vespa velutina* on native wasp species: A first effort to understand population-level effects in an invaded area of Europe. Journal of Insect Conservation 26: 663–671. https://doi.org/10.1007/s10841-022-00405-3

Cogalniceanu D, Skolka M, Stanescu F, Tudor M, Memedemin D, Preda C, Wong L, Pagad S (2020) Global Register of Introduced and Invasive Species - Romania. https://cloud.gbif.org/griis/resource?r=griis-romania&v=1.3 [September 7, 2025]

Colling G, Glaser M, Buholzer S, Bürger J, Chytrý M, Fanfarillo E, Follak S, Jansen F, Kolářová M, Küzmič F, Lososová Z, Schumacher M, Šilc U, Wietzke A, Dullinger S, Essl F (2025) Ninety years of alien plant species accumulation across regional and local scales in central European fields. Agriculture, Ecosystems & Environment 383: 109483. https://doi.org/10.1016/j.agee.2025.109483

Convention on Biological Diversity (2014) Pathways of introduction of invasive species, their prioritization and management. In: UNEP/CBD/SBSTTA/18/9/Add. 1. Montréal: Secretariat of the Convention on Biological Diversity. Convention on Biological Diversity Montreal, QC, Canada.

Convention on Biological Diversity (2022) Kunming-Montreal Global Biodiversity Framework: Target 6 Reduce the Introduction of Invasive Alien Species by 50% and Minimize Their Impact. https://www.cbd.int/gbf/targets/6

Díaz-Calafat J, Jaume-Ramis S, Soacha K, Álvarez A, Piera J (2024) Revealing biases in insect observations: a comparative analysis between academic and citizen science data. PLoS ONE 19: e0305757. https://doi.org/10.1371/journal.pone.0305757

Dragan O, Rozylowicz L, Ureche D, Falka I, Cogălniceanu D (2024) Invasive fish species in Romanian freshwater. A review of over 100 years of occurrence reports. Neobiota 94: 15–30. https://doi.org/10.3897/neobiota.94.117313

ESRI (2025a) ArcGIS Pro 3.5.3. ESRI, Redlands, CA, USA. https://www.esri.com/ [September 8, 2025]

ESRI (2025b) Optimized Hot Spot Analysis (Spatial Statistics). https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-statistics/optimized-hot-spot-analysis.htm

Essl F, Bacher S, Genovesi P, Hulme PE, Jeschke JM, Katsanevakis S, Kowarik I, Kühn I, Pyšek P, Rabitsch W (2018) Which taxa are alien? Criteria, applications, and uncertainties. BioScience 68: 496–509. https://doi.org/10.1093/biosci/biy057

European Commission (2020) EU Biodiversity Strategy for 2030: Bringing nature back into our lives. COM(2020) 380 final, Brussels: European Commission. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52020DC0380

European Commission (2025) Commission implementing Regulation (EU) 2025/1422 of 17 July 2025 amending Implementing Regulation (EU) 2016/1141 to update the list of invasive alien species of Union concern. Official Journal of the European Union L. http://data.europa.eu/eli/reg_impl/2025/1422/oj

European Topic Centre (2008) Europe's biodiversity – biogeographical regions and seas. European Environment Agency, Copenhagen, 23 pp. https://www.eea.europa.eu/en/analysis/publications/report_2002_0524_154909 [July 30, 2025]

Garcia-Lozano C, Pueyo-Ros J, Canelles Q, Latombe G, Adriaens T, Bacher S, Cardoso AC, Cleary M, Coromina L, Courchamp F, Dawson W, de Groot M, Essl F, Gallardo B, Golivets M, Huusela E, Jauni M, Jelaska SD, Jeschke JM, Katsanevakis S, Kourantidou M, Kühn I, Lenzner B, Leung B, Marchante E, O'Flynn C, Pérez-Granados C, Pergl J, Pipek P, Preda C, Ribeiro F, Roy H, Scalera R, von Schmalensee M, Seebens H, Stefánsson RA, Tokarska-Guzik B, Tricarico E, Vanderhoeven S, Vandvik V, Vilà M, Roura-Pascual N (2025) Management Measures and Trends of Biological Invasions in Europe: A Survey-Based Assessment of Local Managers. Global Change Biology 31: e70028. https://doi.org/10.1111/gcb.70028

GBIF (2025) GBIF Occurrence Download. https://doi.org/10.15468/dl.g77t4g

GBIF Secretariat (2023) GBIF Backbone Taxonomy. Checklist dataset. GBIF.org. https://doi.org/10.15468/39omei [July 30, 2025]

Genovesi P, Carboneras C, Vilà M, Walton P (2015) EU adopts innovative legislation on invasive species: a step towards a global response to biological invasions? Biological Invasions 17: 1307–1311. https://doi.org/10.1007/s10530-014-0817-8

Getis A, Ord JK (2010) The Analysis of Spatial Association by Use of Distance Statistics. In: Anselin L, Rey SJ (Eds) Perspectives on Spatial Data Analysis, 127–145. https://doi.org/10.1007/978-3-642-01976-0_10

Gomoiu MT, Skolka M (1998) Cresterea biodiversitatii prin imigrare-noi specii in fauna Romaniei. Analele Universității Ovidius Constanța - seria Biologie-Ecologie 2: 181–202.

Groom Q, Strubbe D, Adriaens T, Davis AJ, Desmet P, Oldoni D, Reyserhove L, Roy HE, Vanderhoeven S (2019) Empowering citizens to inform decision-making as a way forward to support invasive alien species policy. Citizen Science: Theory and Practice 4. https://doi.org/10.5334/cstp.238

Groom Q, Adriaens T, Desmet P, Vanderhoeven S, Yovcheva N (2025a) Why countries need the Global Biodiversity Information Facility: Lessons from Belgium. Zenodo. https://doi.org/10.5281/zenodo.17023159

Groom Q, Adriaens T, August T, Capinha C, Cardoso AS, Dehnen-Schmutz K, Essl F, Franklin A, Golivets M, Gonçalves J (2025b) OneSTOP: OneBiosecurity systems and technology for people, places and pathways. Research Ideas and Outcomes 11: e165316. https://doi.org/10.3897/rio.11.e165316

Groom QJ, Adriaens T, Desmet P, Simpson A, De Wever A, Bazos I, Cardoso AC, Charles L, Christopoulou A, Gazda A (2017) Seven recommendations to make your invasive alien species data more useful. Frontiers in Applied Mathematics and Statistics 3: 13. https://doi.org/10.3389/fams.2017.00013

Hänfling B, Edwards F, Gherardi F (2011) Invasive alien Crustacea: dispersal, establishment, impact and control. BioControl 56: 573–595. https://doi.org/10.1007/s10526-011-9380-8

Haubrock PJ, Cuthbert RN, Haase P (2023) Long-term trends and drivers of biological invasion in Central European streams. Science of The Total Environment 876: 162817. https://doi.org/10.1016/j.scitotenv.2023.162817

Haubrock PJ, Tarkan AS, Błońska D, Gora A, Parvulescu L, Kouba A, Soto I (2025) Prioritising Non-Native Crayfish Species for Management in the Rhine-Main Observatory Using the Dispersal-Origin-Status-Impact (DOSI) Scheme. Aquatic Conservation: Marine and Freshwater Ecosystems 35: e70191. https://doi.org/10.1002/aqc.70191

Haye T, Gariepy T, Hoelmer K, Rossi J-P, Streito J-C, Tassus X, Desneux N (2015) Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide. Journal of Pest Science 88: 665–673. https://doi.org/10.1007/s10340-015-0670-2

Herborg L-M, Rushton SP, Clare AS, Bentley MG (2003) Spread of the Chinese mitten crab (*Eriocheir sinensis* H. Milne Edwards) in Continental Europe: analysis of a historical data set. Hydrobiologia 503: 21–28. https://doi.org/10.1023/B:HYDR.0000008483.63314.3c

Hulme PE (2009) Trade, transport and trouble: managing invasive species pathways in an era of globalization. Journal of Applied Ecology 46: 10–18. https://doi.org/10.1111/j.1365-2664.2008.01600.x

iNaturalist community (2025) Observations of introduced species from Romania, Romania observed between 1990-2023. https://www.inaturalist.org [July 31, 2025]

IPBES (2023) Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. In: Roy HE, Pauchard A, Stoett P, Renard Truong T, Bacher S, Galil BS, Hulme PE, Ikeda T, Sankaran KV, McGeoch MA, Meyerson LA, Nuñez MA, Ordonez A, Rahlao SJ, Schwindt E, Seebens H, Sheppard AW, Vandvik V (Eds) IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.7430692

Isaac NJB, Pocock MJO (2015) Bias and information in biological records. Biological Journal of the Linnean Society 115: 522–531. https://doi.org/10.1111/bij.12532

Katsanevakis S, Deriu I, D'amico F, Nunes AL, Sanchez SP, Crocetta F, Arianoutsou M, Bazos I, Christopoulou A, Curto G (2015) European alien species information network (EASIN): supporting European policies and scientific research. Management of Biological Invasions 6: 147. https://doi.org/10.3391/mbi.2015.6.2.05

Katsanevakis S, Zaiko A, Olenin S, Costello MJ, Gallardo B, Tricarico E, Adriaens T, Jeschke JM, Sini M, Burke N (2024) GuardIAS–Guarding European waters from invasive alien species. Management of Biological Invasions. https://doi.org/10.3391/mbi.2024.15.4.14

Koch W, Hogeweg L, Nilsen EB, O'Hara RB, Finstad AG (2023) Recognizability bias in citizen science photographs. Royal Society Open Science 10: 221063. https://doi.org/10.1098/rsos.221063

Latombe G, Pyšek P, Jeschke JM, Blackburn TM, Bacher S, Capinha C, Costello MJ, Fernández M, Gregory RD, Hobern D (2017) A vision for global monitoring of biological invasions. Biological Conservation 213: 295–308. https://doi.org/10.1016/j.biocon.2016.06.013

Leuven RS, van der Velde G, Baijens I, Snijders J, van der Zwart C, Lenders HR, bij de Vaate A (2009) The river Rhine: a global highway for dispersal of aquatic invasive species. Biological invasions 11: 1989–2008. https://doi.org/10.1007/s10530-009-9491-7

Linlin Y (2023) ggvenn: Draw Venn Diagram by "ggplot2". R package version 0.1.10. https://CRAN.R-project.org/package=ggvenn

Lorincz I (2024) Obama Flatworm (*Obama nungara*). https://www.inaturalist.org/observations/229758688 [September 25, 2025]

Maiakovska O, Andriantsoa R, Tönges S, Legrand C, Gutekunst J, Hanna K, Parvulescu L, Novitsky R, Weiperth A, Sciberras A (2021) Genome analysis of the monoclonal marbled crayfish reveals genetic separation over a short evolutionary timescale. Communications biology 4: 74. https://doi.org/10.1038/s42003-020-01588-8

Mann J (1866) Aufzählung der im Jahre 1865 in der Dobrudscha gesammelten Schmetterlinge. Verhandlungen der kk zoologisch-botanischen Gesellschaft Wien 16: 1–40. https://www.zobodat.at/pdf/VZBG_16_0321-0360.pdf

McGeoch MA, Spear D, Kleynhans EJ, Marais E (2012) Uncertainty in invasive alien species listing. Ecological Applications 22: 959–971. https://doi.org/10.1890/11-1252.1

MEFW (2022) Invasive species management in Romania according to Regulation (EU) 1143/2014 on the prevention and management of the introduction and spread of invasive alien species. SMIS 120008. Regional Development Fund – The Large Infrastructure Operational Programme 2014-2020 (POIM). https://invazive.ccmesi.ro/ [July 30, 2025]

Memedemin D, Anastasiu P, Preda C, Negrean G, Cogalniceanu D (2016) Alien plant species turnover in Constanța harbor (Romania) in the last decade. Acta Horti Botanici Bucurestiensis 43: 5–18.

Micu S, Micu D (2006) Proposed IUCN regional status of all Crustacea: Decapoda from the Romanian Black Sea. Analele Ştiinţifice ale Universităţii „Al. I. Cuza" Iaşi, seria Biologie animală 52: 7–38.

Mojžišová M, Svobodová J, Kozubíková-Balcarová E, Štruncová E, Stift R, Bílý M, Kouba A, Petrusek A (2022) Long-term changes in the prevalence of the crayfish plague pathogen and its genotyping in invasive crayfish species in Czechia. NeoBiota 74: 105–127. https://doi.org/10.3897/neobiota.74.79087

Nunes A, Venter T, Adriaens T, Costello K, Delva S, Gospodinov K, Novoa A, Peyton A, Pyšek P, Rabitsch W, Roy H, Scalera R, Smith K, Tricarico E, Aldridge D, Altamirano M, Bellotto V, Bertolino S, Brundu G, Cardoso A, Cavadino I, Dawson W, Demetriou J, Devisscher S, D'hondt B, Essl F, Evans T, Everts T, Gallardo B, García-Berthou E, Groom Q, Hillaert J, Jacobs A, Katsanevakis S, Marchante E, Marchini A, Oficialdegui F, Olenin S, O'Riordan R, Pattison Z, Petersen F, Preda C, Rebelo R, Reniers J, Scheers K, Skuhrovec J, Solarz W, Steen F, Strubbe D, van Landuyt W, van Valkenburg J, Verëll V, Verhelst P, Verreycken H (2025) Invasive alien species horizon scanning in support of implementation of Regulation 1143/2014 – Final study report. Publications Office of the European Union.

Oţel V (2004) The presence of *Eriocheir sinensis* Milne Edwards, 1835 (Crustacea, Decapoda) in the Danube Delta Biosphere Reserve area. Analalele Ştiinţifice ale Institutului Naţional de Cercetare-Dezvoltare „Delta Dunării", Tulcea 10: 45–48.

Parvulescu L (2019) Introducing a new *Austropotamobius* crayfish species (Crustacea, Decapoda, Astacidae): A Miocene endemism of the Apuseni Mountains, Romania. Zoologischer Anzeiger 279: 94–102. https://doi.org/10.1016/j.jcz.2019.01.006

Parvulescu L, Palos C, Molnar P (2009) First record of the spiny-cheek crayfish *Orconectes limosus* (Rafinesque, 1817) (Crustacea: Decapoda: Cambaridae) in Romania. North-Western Journal of Zoology 5: 424–428.

Parvulescu L, Togor A, Lele S-F, Scheu S, Şinca D, Panteleit J (2017) First established population of marbled crayfish *Procambarus fallax* (Hagen, 1870) f. *virginalis* (Decapoda, Cambaridae) in Romania. BioInvasions Records 6: 357–362. https://doi.org/10.3391/bir.2017.6.4.09

Pindaru LC, Nita A, Niculae IM, Manolache S, Rozylowicz L (2023) More streamlined and targeted. A comparative analysis of the 7th and 8th Environment Action Programmes guiding European environmental policy. Heliyon 9. https://doi.org/10.1016/j.heliyon.2023.e19212

Pocock MJ, Tweddle JC, Savage J, Robinson LD, Roy HE (2017) The diversity and evolution of ecological and environmental citizen science. PLoS ONE 12: e0172579. https://doi.org/10.1371/journal.pone.0172579

Pocock MJO, Adriaens T, Bertolino S, Eschen R, Essl F, Hulme PE, Jeschke JM, Roy HE, Teixeira H, de Groot M (2024) Citizen science is a vital partnership for invasive alien species management and research. iScience 27. https://doi.org/10.1016/j.isci.2023.108623

Popa LO, Popa OP, Iorgu EI, Krapal AM, Parvulescu L, Surugiu V, Petrescu I, Petrescu AM, Stefan A, Motoc RM, Brezeneanu AM, Irimia AG (2020) Ghid de inventariere şi cartare a distribuţiei speciilor de nevertebrate dulcicole alogene invazive din România. Zenodo. https://doi.org/10.5281/zenodo.5804099

Popa OP, Popa LO, Sahlean TC, Banaduc AM, Banaduc DS, Brezeanu AM, Cioboiu O, Cupsa D, Gavril V, Ilie MD, Iurgu IE, Irimiea AG, Krapa AM, Motoc MR, Olosutean H, Parvulescu L, Perju M, Petrescu AM, Petrescu I, Petrovici M, Popescu Mirceni RV, Surugiu V, Stanciu RC, Stefan A, Zaharia R (2022) Raport final privind distribuția speciilor de nevertebrate de apă dulce alogene din hotspot-uri și căile prioritare de pătrundere (an 3). Zenodo. https://doi.org/10.5281/zenodo.7345137

Popa OP, Popa LO, Sahlean TC, Banaduc AM, Banaduc DS, Brezeanu AM, Cioboiu O, Cupsa D, Gavril V, Ilie MD, Iurgu IE, Irimiea AG, Krapa AM, Motoc MR, Olosutean H, Parvulescu L, Perju M, Petrescu AM, Petrescu I, Petrovici M, Popescu Mirceni RV, Surugiu V, Stanciu RC, Stefan A, Zaharia R (2023) Raport final privind distribuția speciilor de nevertebrate de apă dulce alogene rezultată din activitatea de inventariere cu efort redus (an 3). Zenodo. https://doi.org/10.5281/zenodo.8224394

Popescu Mirceni VR, Surugiu V, Petrescu AM, Petrescu I, Balcu M-J, Sahlean TC, Zaharia R (2022) Raport final privind distribuția speciilor de animale marine alogene rezultată din activitatea de inventariere cu efort redus (an 3 cartare). Zenodo. https://doi.org/10.5281/zenodo.7155672

Popescu Mirceni VR, Surugiu V, Petrescu AM, Petrescu I, Balcu M-J, Sahlean TC, Zaharia R (2023) Raport final privind distribuția speciilor de animale marine alogene din hot-spot-uri și căile prioritare de pătrundere (an 3 cartare). Zenodo. https://doi.org/10.5281/zenodo.8224948

Posea G, Badea L (1984) România. Unitățile de relief (Regionarea geomorfologică). Editura Științifică și Enciclopedică, București.

Preda C, Groom Q (2021) *Vespa velutina* interactions from literature. https://doi.org/10.5281/zenodo.5501763

Preda C, Memedemin D, Skolka M, Cogălniceanu D (2012) Early detection of potentially invasive invertebrate species in *Mytilus galloprovincialis* Lamarck, 1819 dominated communities in harbours. Helgoland Marine Research 66: 545–556. https://doi.org/10.1007/s10152-012-0290-7

Preda C, Adam C, Constantinescu IC, Popa OP, Popa LO, Balcu MJ, Brezeanu AM, Dascalu MM, Draghici AC, Gavrilescu CF, Gavrilidis AA, Gheoca V, Iorgu EI, Iorgu IS, Krapal AM, Maican S, Manci CO, Manta N, Manu M, Motoc RM, Niculae IM, Petrescu AM, Pintilioaie AM, Popa AF, Radac IA, Rozylowicz L, Ruicanescu A, Sahlean TC, Surugiu V, Serban C, Stefan A, Szekely L, Tausan I, Skolka M (2026) From soil to stream and sea: species richness and distribution of alien invertebrates in Romania. NeoBiota. Occurrence dataset. https://ipt.pensoft.net/resource?r=alieninvro

Price-Jones V, Brown PM, Adriaens T, Tricarico E, Farrow RA, Gervasini E, Groom Q, Reyserhove L, Schade S, Tsinaraki C (2022) Eyes on the aliens: citizen science contributes to research, policy and management of biological invasions in Europe. NeoBiota 78: 1–24. https://doi.org/10.3897/neobiota.78.81476

Pyšek P, Danihelka J, Sádlo J, Chrtek J, Chytrý M, Jarošík V, Kaplan Z, Krahulec F, Moravcová L, Pergl J (2012) Catalogue of alien plants of the Czech Republic: checklist update, taxonomic diversity and invasion patterns. Preslia 84(2): 155–255.

Pyšek P, Hulme PE, Meyerson LA, Smith GF, Boatwright JS, Crouch NR, Figueiredo E, Foxcroft LC, Jarošík V, Richardson DM (2013) Hitting the right target: taxonomic challenges for, and of, plant invasions. AoB Plants 5: plt042. https://doi.org/10.1093/aobpla/plt042

Pyšek P, Hulme PE, Simberloff D, Bacher S, Blackburn TM, Carlton JT, Dawson W, Essl F, Foxcroft LC, Genovesi P, Jeschke JM, Kühn I, Liebhold AM, Mandrak NE, Meyerson LA, Pauchard A, Pergl J, Roy HE, Seebens H, van Kleunen M, Vilà M, Wingfield MJ, Richardson DM (2020) Scientists' warning on invasive alien species. Biological Reviews 95: 1511–1534. https://doi.org/10.1111/brv.12627

R Core Team (2026) R: A language and environment for statistical computing. R Foundation for Statistical Computing. https://www.R-project.org

Renault D, Angulo E, Cuthbert RN, Haubrock PJ, Capinha C, Kramer AM, Courchamp F (2022) The magnitude, diversity, and distribution of the economic costs of invasive terrestrial invertebrates worldwide. Science of the Total Environment 835: 155391. https://doi.org/10.1016/j.scitotenv.2022.155391

Reyserhove L, Desmet P, Oldoni D, Adriaens T, Strubbe D, Davis AJ, Vanderhoeven S, Verloove F, Groom Q (2020) A checklist recipe: making species data open and FAIR. Database 2020: baaa084. https://doi.org/10.1093/database/baaa084

Robertson T, Döring M, Guralnick R, Bloom D, Wieczorek J, Braak K, Otegui J, Russell L, Desmet P (2014) The GBIF integrated publishing toolkit: facilitating the efficient publishing of biodiversity data on the internet. PLoS ONE 9: e102623. https://doi.org/10.1371/journal.pone.0102623

Robinet C, Suppo C, Darrouzet E (2017) Rapid spread of the invasive yellow-legged hornet in France: the role of human-mediated dispersal and the effects of control measures. Journal of Applied Ecology 54: 205–215. https://doi.org/10.1111/1365-2664.12724

Roessink I, van der Zon KAE, de Reus SRMM, Peeters ETHM (2022) Native European crayfish *Astacus astacus* competitive in staged confrontation with the invasive crayfish *Faxonius limosus* and *Procambarus acutus*. PLoS ONE 17(1): e0263133. https://doi.org/10.1371/journal.pone.0263133

Roques A, Rabitsch W, Rasplus J-Y, Lopez-Vaamonde C, Nentwig W, Kenis M (2009) Alien terrestrial invertebrates of Europe. In: DAISIE (Ed.), Handbook of Alien Species in Europe. Invading Nature - Springer Series in Invasion Ecology. Springer, 63–79. https://doi.org/10.1007/978-1-4020-8280-1_5

Roques A, Kenis M, Lees D, Lopez-Vaamonde C, Rabitsch W, Rasplus JY, Roy DB [Eds] (2010) Alien terrestrial arthropods of Europe. BioRisk 4 (Special Issue), 2 volumes. Pensoft Publishers, Sofia, 1028 pp.

Roques A, Auger-Rozenberg MA, Blackburn TM, Garnas J, Pyšek P, Rabitsch W, Richardson DM, Wingfield MJ, Liebhold AM, Duncan RP (2016) Temporal and interspecific variation in rates of spread for insect species invading Europe during the last 200 years. Biological Invasions 18: 907–920. https://doi.org/10.1007/s10530-016-1080-y

Roy HE, Bacher S, Essl F, Adriaens T, Aldridge DC, Bishop JDD, Blackburn TM, Branquart E, Brodie J, Carboneras C, Cottier-Cook EJ, Copp GH, Dean HJ, Eilenberg J, Gallardo B, Garcia M, García-Berthou E, Genovesi P, Hulme PE, Kenis M, Kerckhof F, Kettunen M, Minchin D, Nentwig W, Nieto A, Pergl J, Pescott OL, Peyton JM, Preda C, Roques A, Rorke SL, Scalera R, Schindler S, Schönrogge K, Sewell J, Solarz W, Stewart AJA, Tricarico E, Vanderhoeven S, van der Velde G, Vilà M, Wood CA, Zenetos A, Rabitsch W (2019) Developing a list of invasive alien species likely to threaten biodiversity and ecosystems in the European Union. Global Change Biology 25: 1032–1048. https://doi.org/10.1111/gcb.14527

Roy HE, Pauchard A, Stoett PJ, Renard Truong T, Meyerson LA, Bacher S, Galil BS, Hulme PE, Ikeda T, Kavileveettil S, McGeoch MA, Nuñez MA, Ordonez A, Rahlao SJ, Schwindt E, Seebens H, Sheppard AW, Vandvik V, Aleksanyan A, Ansong M, August T, Blanchard R, Brugnoli E, Bukombe JK, Bwalya B, Byun C, Camacho-Cervantes M, Cassey P, Castillo ML, Courchamp F, Dehnen-Schmutz K, Zenni RD, Egawa C, Essl F, Fayvush G, Fernandez RD, Fernandez M, Foxcroft LC, Genovesi P, Groom QJ, González AI, Helm A, Herrera I, Hiremath AJ, Howard PL, Hui C, Ikegami M, Keskin E, Koyama A, Ksenofontov S, Lenzner B, Lipinskaya T, Lockwood JL, Mangwa DC, Martinou AF, McDermott SM, Morales CL, Müllerová J, Mungi NA, Munishi LK, Ojaveer H, Pagad SN, Pallewatta NPKTS, Peacock LR, Per E, Pergl J, Preda C, Pyšek P, Rai RK, Ricciardi A, Richardson DM, Riley S, Rono BJ, Ryan-Colton E, Saeedi H, Shrestha BB, Simberloff D, Tawake A, Tricarico E, Vanderhoeven S, Vicente J, Vilà M, Wanzala W, Werenkraut V, Weyl OLF, Wilson JRU, Xavier RO, Ziller SR (2024) Curbing the major and growing threats from invasive alien species is urgent and achievable. Nature Ecology & Evolution 8: 1216–1223. https://doi.org/10.1038/s41559-024-02412-w

Rudnick D, Resh V (2005) Stable isotopes, mesocosms and gut content analysis demonstrate trophic differences in two invasive decapod crustacea. Freshwater Biology 50: 1323–1336. https://doi.org/10.1111/j.1365-2427.2005.01398.x

Ruiz GM, Fofonoff PW, Carlton JT, Wonham MJ, Hines AH (2000) Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. Annual review of ecology and systematics 31: 481–531. https://doi.org/10.1146/annurev.ecolsys.31.1.481

Sánchez O, Oficialdegui FJ, Torralba-Burrial A, Arbesú R, Valle-Artaza JM, Fernández-González Á, Ardura A, Arias A (2024) *Procambarus virginalis* Lyko, 2017: A new threat to Iberian inland waters. Ecology and Evolution 14: e11362. https://doi.org/10.1002/ece3.11362

Schrimpf A, Chucholl C, Schmidt T, Schulz R (2013) Crayfish plague agent detected in populations of the invasive North American crayfish *Orconectes immunis* (Hagen, 1870) in the Rhine River, Germany. Aquatic Invasions 8: 103–109. https://doi.org/10.3391/ai.2013.8.1.12

Schrimpf A, Schmidt T, Schulz R (2014) Invasive Chinese mitten crab (*Eriocheir sinensis*) transmits crayfish plague pathogen (*Aphanomyces astaci*). Aquatic Invasions 9(2): 203–209. https://doi.org/10.3391/ai.2014.9.2.09

Schrimpf A, Piscione M, Cammaerts R, Collas M, Herman D, Jung A, Ottburg F, Roessink I, Rollin X, Schulz R (2017) Genetic characterization of Western European noble crayfish populations (*Astacus astacus*) for advanced conservation management strategies. Conservation Genetics 18: 1299–1315. https://doi.org/10.1007/s10592-017-0981-3

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pyšek P, Winter M, Arianoutsou M, Bacher S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jäger H, Kartesz J, Kenis M, Kreft H, Kühn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerová K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T, Essl F (2017) No saturation in the accumulation of alien species worldwide. Nature Communications 8: 14435. https://doi.org/10.1038/ncomms14435

Seebens H, Clarke DA, Groom Q, Wilson JR, García-Berthou E, Kühn I, Roigé M, Pagad S, Essl F, Vicente J (2020) A workflow for standardising and integrating alien species distribution data. NeoBiota 59: 39–59. https://doi.org/10.3897/neobiota.59.53578

Seebens H, Bacher S, Blackburn TM, Capinha C, Dawson W, Dullinger S, Genovesi P, Hulme PE, van Kleunen M, Kühn I, Jeschke JM, Lenzner B, Liebhold AM, Pattison Z, Pergl J, Pyšek P, Winter M, Essl F (2021) Projecting the continental accumulation of alien species through to 2050. Global Change Biology 27: 970–982. https://doi.org/10.1111/gcb.15333

Škraba D, Tošić A, Miličić D, Nikolić V, Simonović P (2013) Invasiveness assessment of the Chinese mitten crab *Eriocheir sinensis* (H. Milne Edwards, 1853) in the Serbian section of the river Danube. Archives of Biological Sciences 65: 353–358. https://doi.org/10.2298/ABS1301353S

Smith KG, Nunes AL, Aegerter J, Baker SE, Di Silvestre I, Ferreira CC, Griffith M, Lane J, Muir A, Binding S, Broadway M, Robertson PA, Scalera R, Adriaens T, Åhlén P-A, Aliaga A, Baert K, Bakaloudis DE, Bertolino S, Briggs L, Cartuyvels E, Dahl F, D'hondt B, Eckert M, Gethöffer F, Gojdičová E, Huysentruyt F, Jelić D, Lešová A, Lužnik M, Moreno L, Nagy G, Poledník L, Preda C, Skorupski J, Telnov D, Trichkova T, Verreycken H, Vucić M (2022) Appendices on management measure assessments - A manual for the management of vertebrate invasive alien species of Union concern, incorporating animal welfare. 1st Edition.Technical report prepared for the European Commission within the framework of the contract no. 07.027746/2019/812504/SER/ENV.D.2.

Soto I, Macêdo RL, Carneiro L, Briski E, Kouba A, Cuthbert RN, Haubrock PJ (2024) Divergent temporal responses of native macroinvertebrate communities to biological invasions. Global Change Biology 30: e17521. https://doi.org/10.1111/gcb.17521

Surugiu V, Petrescu A-M, Petrescu I, Balcu M-J, Popescu Mirceni RV, Sahlean CT, Ciubuc F, Popa A-M (2022) Ghid de inventariere şi cartare a distribuţiei speciilor de animale marine invazive şi potențial invazive din România. Zenodo. https://doi.org/10.5281/zenodo.6833020

Trichkova T, Paunović M, Skolka M, Kenderov L, Hubenov Z, Evtimova V, Cardeccia A, Popa L, Popa O, Tomović J (2014) The Danube River as an invasive alien species corridor: The Lower Danube case study. In: Book of abstracts: IAD 40th Anniversary Conference: The Danube and Black Sea Region: Unique Environment and Human Well-Being Under Conditions of Global Changes; 2014 Jun 17–20; Sofia, Bulgaria. Sofia: Bulgarian Academy of Sciences, Institute of Biodiversity and Ecosystem Research, 37–37.

Trichkova T, Kutsarov Y, Todorov M, Puky M, Hubenov Z (2017) The Chinese mitten crab *Eriocheir sinensis* H. Milne Edwards, 1853 (Crustacea: Decapoda: Varunidae), a new invasive alien species to the Bulgarian fauna. Acta Zoologica Bulgarica 9: 149–154.

Troudet J, Grandcolas P, Blin A, Vignes-Lebbe R, Legendre F (2017) Taxonomic bias in biodiversity data and societal preferences. Scientific Reports 7: 9132. https://doi.org/10.1038/s41598-017-09084-6

Ragkousis M, Zenetos A, Souissi JB et al. (2023) Unpublished Mediterranean and Black Sea records of marine alien, cryptogenic, and neonative species. BioInvasions Records 12: 339–369. https://doi.org/10.3391/bir.2023.12.2.01

Wickham H (2016) Elegant Graphics for Data Analysis. ggplot2. Springer-Verlag New York. https://doi.org/10.1007/978-3-319-24277-4_9

Wickham H, Francois R, Henry L, Müller K, Vaughan R (2014) dplyr: A Grammar of Data Manipulation. R package version 1.1.4. https://doi.org/10.32614/CRAN.package.dplyr

Wieczorek J, Bloom D, Guralnick R, Blum S, Döring M, Giovanni R, Robertson T, Vieglais D (2012) Darwin Core: An Evolving Community-Developed Biodiversity Data Standard. PLoS ONE 7: e29715. https://doi.org/10.1371/journal.pone.0029715

Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Artificial Intelligence (AI) use

The authors accept full responsibility for the content of the manuscript, including the disclosure of any use of AI.
No AI tools were used in the preparation of this manuscript.

Funding

This work was supported by OneStop OneBiosecurity Systems and Technology for People, Places and Pathways, Horizon Europe Research and Innovation Programme, ID 101180559; ResPonSe, PNRR-III-C9-2022-I5, Romanian Ministry of Research, Innovation and Digitalization, project no. 760010; Invasive species management in Romania according to REGULATION (EU) 1143/2014 on the prevention and management of the introduction and spread of invasive alien species, Ministry of Investments and European Projects, POIM SMIS 120008/2019; B3 (Biodiversity Building Blocks for policy), Horizon Europe Research and Innovation Programme, ID 101059592. A.M. Pintilioaie's work was partially supported through the Operational Program Competitiveness 2014–2020, Axis 1, under POC/448/1/1 Research infrastructure projects for public R&D institutions/Sections F 2018, through the Research Center with Integrated Techniques for Atmospheric Aerosol Investigation in Romania (RECENT AIR) project, under grant agreement MySMIS 127324. Manu M.'s work was partially supported by project number RO1567-IBB01/2025 Romanian Academy, Institute of Biology Bucharest.

Author contributions

Conceptualization: CP, LR. Data curation: CP, CA, ICC, OPP, LOP, MJB, AMB, MMD, ACD, CFG, AAG, VG, EII, IȘI, AMK, SM, COM, NM, MM, RMM, IMN, AMPe, AMPi, AFP, IAR, LR, AR, TCS, VS, CȘ, AȘ, LS, IT, MS. Formal analysis: CP, CA, ICC, OPP, LOP, AAG, IMN, LR, TCS, MS. Funding acquisition: CP, NM. Investigation: CP, CA, ICC, OPP, LOP, MJB, AMB, MMD, ACD, CFG, VG, EII, IȘI, AMK, SM, COM, MM, RMM, AMPe, AMPi, AFP, IAR, AR, VS, CȘ, AȘ, LS, IT, MS. Methodology: CP, CA, ICC, OPP, LOP, NM, LR, MS. Project administration: CP, NM. Software: CP, LR. Visualization: AAG, IMN, LR, TCS. Writing - original draft: CP, CA, ICC, OPP, LOP, LR, MS. Writing - review and editing: CP, CA, ICC, OPP, LOP, MJB, AMB, MMD, ACCD, CFG, AAG, VG, EII, IȘI, AMK, SM, COM, NM, MM, RMM, IMN, AMPe, AMPi, AFP, IAR, LR, AR, TCS, VS, CȘ, AȘ, LS, IT, MS. CP, CA, ICC, OPP, LOP, MS contributed equally to this work.

Author ORCIDs

C. Preda https://orcid.org/0000-0002-3513-7344
C. Adam https://orcid.org/0000-0002-6060-4602
I.C. Constantinescu https://orcid.org/0000-0003-4671-8379
O.P. Popa https://orcid.org/0000-0003-3099-8193
L.O. Popa https://orcid.org/0000-0003-3458-4692
M.-J. Bâlcu https://orcid.org/0009-0007-7043-2457
M.-M. Dascălu https://orcid.org/0000-0003-3045-8306
A.-C. Drăghici https://orcid.org/0000-0003-4663-6971
C.F. Gavrilescu https://orcid.org/0000-0001-9545-1936
A.A. Gavrilidis https://orcid.org/0000-0002-1628-6897
V. Gheoca https://orcid.org/0000-0002-1188-7116
E.I. Iorgu https://orcid.org/0000-0003-4438-140X
I.Ș. Iorgu https://orcid.org/0000-0002-4609-0051
A.M. Krapal https://orcid.org/0009-0007-0366-9550
S. Maican https://orcid.org/0000-0002-4885-6559
C.-O. Manci https://orcid.org/0000-0003-0267-2460
N. Manta https://orcid.org/0000-0003-0057-9684
M. Manu https://orcid.org/0000-0002-4372-8208
R.M. Motoc https://orcid.org/0000-0002-2724-8458
I.M. Niculae https://orcid.org/0000-0001-7340-6835
A.-M. Petrescu https://orcid.org/0000-0001-9553-3587
A.-M. Pintilioaie https://orcid.org/0000-0002-3119-5803
A.F. Popa https://orcid.org/0000-0002-7194-5971
I.A. Rădac https://orcid.org/0000-0002-7271-5051
L. Rozylowicz https://orcid.org/0000-0001-7174-032X
A. Ruicănescu https://orcid.org/0000-0002-8400-998X
T.C. Sahlean https://orcid.org/0000-0001-9014-9084
V. Surugiu https://orcid.org/0000-0003-4933-7678
C. Șerban https://orcid.org/0000-0002-6754-7954
A. Ștefan https://orcid.org/0000-0003-2339-210X
I. Tăușan https://orcid.org/0000-0002-9599-1761
M. Skolka https://orcid.org/0000-0002-1598-604X

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

Supplementary material 1

Annex 1 – References used to extract occurrence data

Authors: Cristina Preda, Costică Adam, Ioana Cristina Constantinescu, Oana Paula Popa, Luis Ovidiu Popa, Maxim-Jean Bâlcu, Andreea Maria Brezeanu, Maria-Magdalena Dascălu, Andreea-Cătălina Drăghici, Carla F. Gavrilescu, Athanasios Alexandru Gavrilidis, Voichița Gheoca, Elena Iulia Iorgu, Ionuț Ștefan Iorgu, Ana Maria Krapal, Sanda Maican, Cosmin-Ovidiu Manci, Nicolae Manta, Minodora Manu, Rozalia Magda Motoc, Iulian M. Niculae, Ana-Maria Petrescu, Alexandru-Mihai Pintilioaie, Alexandra Florina Popa, Ioan Alexandru Rădac, Laurentiu Rozylowicz, Adrian Ruicănescu, Tiberiu C. Sahlean, Victor Surugiu, Cecilia Șerban, Andrei Ștefan, Levente Székely, Ioan Tăușan, Marius Skolka

Data type: docx

Link: https://doi.org/10.3897/neobiota.108.175337.suppl1

Supplementary material 2

Annex 2 – Checklist of alien invertebrates included in database

Authors: Cristina Preda, Costică Adam, Ioana Cristina Constantinescu, Oana Paula Popa, Luis Ovidiu Popa, Maxim-Jean Bâlcu, Andreea Maria Brezeanu, Maria-Magdalena Dascălu, Andreea-Cătălina Drăghici, Carla F. Gavrilescu, Athanasios Alexandru Gavrilidis, Voichița Gheoca, Elena Iulia Iorgu, Ionuț Ștefan Iorgu, Ana Maria Krapal, Sanda Maican, Cosmin-Ovidiu Manci, Nicolae Manta, Minodora Manu, Rozalia Magda Motoc, Iulian M. Niculae, Ana-Maria Petrescu, Alexandru-Mihai Pintilioaie, Alexandra Florina Popa, Ioan Alexandru Rădac, Laurentiu Rozylowicz, Adrian Ruicănescu, Tiberiu C. Sahlean, Victor Surugiu, Cecilia Șerban, Andrei Ștefan, Levente Székely, Ioan Tăușan, Marius Skolka

Data type: csv

Link: https://doi.org/10.3897/neobiota.108.175337.suppl2

Supplementary material 3

Annex 3 – Checklist of alien species whose presence in Romania requires confirmation

Authors: Cristina Preda, Costică Adam, Ioana Cristina Constantinescu, Oana Paula Popa, Luis Ovidiu Popa, Maxim-Jean Bâlcu, Andreea Maria Brezeanu, Maria Magdalena Dascălu, Andreea-Cătălina Drăghici, Carla F. Gavrilescu, Athanasios Alexandru Gavrilidis, Voichița Gheoca, Elena Iulia Iorgu, Ionuț Ștefan Iorgu, Ana Maria Krapal, Sanda Maican, Cosmin-Ovidiu Manci, Nicolae Manta, Minodora Manu, Rozalia Magda Motoc, Iulian M. Niculae, Ana-Maria Petrescu, Alexandru-Mihai Pintilioaie, Alexandra Florina Popa, Ioan Alexandru Rădac, Laurentiu Rozylowicz, Adrian Ruicănescu, Tiberiu C. Sahlean, Victor Surugiu, Cecilia Șerban, Andrei Ștefan, Levente Székely, Ioan Tăușan, Marius Skolka

Data type: csv

Link: https://doi.org/10.3897/neobiota.108.175337.suppl3