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Distribution and pathways of introduction of invasive alien plant species in Romania

Culita Sirbu[1], Iulia V. Miu[2], Athanasios A. Gavrilidis[2], Simona R. Gradinaru[2], Iulian M. Niculae[2], Cristina Preda[3], Adrian Oprea[4], Mihaela Urziceanu[5], Petronela Camen-Comanescu[5], Eugenia Nagoda[5], Ioana M. Sirbu[6], Daniyar Memedemin[3], Paulina Anastasiu[5,6]

1 *University of Agricultural Sciences and Veterinary Medicine Ion Ionescu de la Brad, Faculty of Agriculture, 3 M. Sadoveanu Alley, Iasi, Romania* **2** *University of Bucharest, Center for Environmental Research and Impact Studies, 1 N. Balcescu, 010041, Bucharest, Romania* **3** *Ovidius University of Constanţa, Department of Natural Sciences, 1 Universităţii Al., Building B, 900470, Constanţa, Romania* **4** *University Al. I. Cuza, Botanic Garden A. Fătu, 7–9 Dumbrava Rosie St., 700487, Iasi, Romania* **5** *University of Bucharest, Botanic Garden D. Brandza, 32 Cotroceni St., 060114, Bucharest, Romania* **6** *University of Bucharest, Faculty of Biology, 91–95 Independenţei Blvd., 050095, Bucharest, Romania*

Corresponding author: Iulia V. Miu (iulia.miu@drd.unibuc.ro)

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Abstract

Biological invasions are one of the main drivers of modern human-induced species losses. Research on the distribution of alien species and their pathways of introduction is essential for understanding and tackling the invasion process. A comprehensive overview on invasive alien plant (IAP) species in Romania is lacking. With this paper, we aim to contribute to filling this gap and to provide a visualization of national patterns regarding plant species invasions, geographical origins and pathways of introductions. Based on plant species occurrence records in the published literature and herbaria we compiled a national database of 102 invasive and potentially invasive alien plant species. We georeferenced 42776 IAP species occurrences and performed an analysis of their spatial patterns. The spatial analyses revealed a biased sampling, with clear hotspots of increased sampling efforts around urban areas. We used chord diagrams to visualize the pathway of introduction and geographical origins of the IAP species, which revealed that species in Romania originate mainly in North and Central America, while the dominant pathway of plant introduction was horticulture. Our results provide an important baseline in drafting management and action plans, as invasive alien plant species represent a priority for the European Union through the Biodiversity Strategy for 2030, and a good starting point for various analyses as the database is further developed and regularly updated.

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Keywords
Hotspot analysis, introduction pathways, national database, occurrence records, plant invasion, species richness

Introduction

Biological invasions are one of the main drivers of modern human-induced species losses (Li et al. 2016; Essl et al. 2020; Pyšek et al. 2020; Seebens et al. 2021). The establishment of invasive alien species (IAS) alters habitats, communities and ecosystems' functioning (Hulme 2015; Bellard et al. 2016), the effects ranging from changes in the physio-chemical environment to increasing the risk of disturbances, such as fires, and contributing to the loss of native biodiversity (Ehrenfeld 2010; Schirmel et al. 2016; Catford et al. 2018). In time, many IAS lead to the decline of abundance of native species (Alyokhin and Sewell 2004) or even to local extinctions, especially when the competition for resources is high (Gallardo et al. 2019).

Invasive alien plants (IAPs) can impact the environment in multiple ways (Barney et al. 2013) and contribute to a wide range of impacts on the economy and human well-being (Diagne et al. 2020). Some IAPs have been shown to disrupt community assemblages (Pyšek et al. 2009) or to alter the biogeochemical processes in an area (Ehrenfeld 2003). In agriculture, IAPs can lead to the loss of crops and productive land (Ruiz and Carlton 2003). Furthermore, they can lead to disease outbreaks for people and wildlife (Kumar Rai and Singh 2020). In past decades, the risks associated with invasive species have increased because human activities altering the environment have escalated rapidly (Keller et al. 2011). In Europe alone, the costs associated with damage and control of the IAP species ragweed (*Ambrosia* spp.) and water-primrose (*Ludwigia* spp.) are estimated to be around 20 USD billion (Haubrock et al. 2021). Most costs are supported by agriculture and forestry, as IAPs are considered agricultural or forestry weeds. However, highly allergenic species to humans, such as the ragweed *Ambrosia artemisiifolia*, lead to high medical costs (Richter et al. 2013).

A good practice in reducing the ecological and social-economic impacts of alien species is to prevent their introduction (Keller et al. 2011). To do this, monitoring species movements and their geographic distribution is necessary to understand and track the effects of biological invasions (McGeoch et al. 2012; McGeoch and Latombe 2015). Occurrence databases represent one of the most simple tools to identify and monitor the distribution of alien plants (Latombe et al. 2017). Reports on biodiversity targets and trends in biological invasions have also been developed using lists of alien and invasive alien species with the aim of informing policy (Hulme et al. 2009). Compiling inventories of alien taxa including details on status and distribution are important for biological invasion research. An up-to date inventory represents an essential tool for conducting risk assessments as well as for guiding policy, management and action plans regarding biological invasions (Hulme et al. 2009).

Globally, the emphasis has been put on the identification and analysis of introduction pathways of IAS as a key step for managing invasive species based on the precautionary principle (Pyšek et al. 2011). The main pathways of introduction and transport of alien species are directly or indirectly associated with anthropogenic activities; the species being introduced intentionally (deliberately) or unintentionally (accidentally). The main introduction pathways of IAS are strongly associated with international trade. The intensification and diversification of commercial activities, and the intensification of transports increase the likelihood of introducing IAS on the territory of certain states (Keller et al. 2011). They can be brought as goods subject to trade or transported by chance on a certain type of goods involuntarily (Hulme 2009; Seebens et al. 2017). To address this issue, decision-makers from various institutions identified the need to develop policies to prevent the spread of IAS, focusing on transcontinental transport and trade (Wołkowycki and Banaszuk 2016).

Due to its geographical position in the center of Europe (Rey et al. 2007) and intensive trade with other states, Romania is prone to biological invasions (Anastasiu and Negrean 2007; Sirbu et al. 2011; Skolka and Preda 2011; Preda et al. 2012; Anastasiu et al. 2017; Stanescu et al. 2020; Urziceanu et al. 2020). According to the Biodiversity Strategy for 2030, managing IAPs is a priority for the European Union (European Commission 2020). As a result, Regulation (EU) No. 1143/2014 focuses on invasive alien species and aims to prevent and limit their negative effects on the environment. Despite the urgency of managing biological invasions, current knowledge on the distribution of alien species in Romania is limited. There are several regional or species-specific studies (Sirbu and Oprea 2010; Szatmari 2012; Zimmermann et al. 2015; Kucsicsa et al. 2018); however, a comprehensive database of alien plant species occurrences at national level is lacking. In order to contribute to filling this gap, the present study aims to review the published records of invasive and potentially invasive plant species in Romania and provide an open-access spatial database, including an overview of the main pathways of introduction.

Methods

To compile a database with invasive and potentially invasive plants species in Romania, we conducted an extensive literature review covering the 1778–2018 time-period. We identified almost 800 alien plant species in Romania but selected only a set of species for the current study (see Suppl. material 1: Appendix S1 for a detailed list). Following the terminology used by Richardson et al. (2000) and Pyšek et al. (2004), our selection refers to alien plants considered invasive, i.e., a subset of naturalized plants that have the potential to spread over large areas, or potentially invasive i.e., naturalized and casual alien plants that may become invasive in Romania. The potentially invasive category refers to alien plants that have established self-sustaining populations (i.e., naturalized) or whose presence has been casually recorded in Romania, without forming such populations (i.e., casual) according to Anastasiu and Negrean (2009) and

Sirbu and Oprea (2011b). Nevertheless, having a history of invasiveness in other European countries, the latter category was considered important for detailed assessments by national experts (e.g., based on the input of all academic botanists in the country, covering all university centers), during a workshop aiming at identifying alien species of national concern, as a part of a national program to support the implementation of Regulation (EU) 1143/2014 on invasive alien species. Therefore, invasive and potentially invasive are considered a single group (hereafter IAP species).

Information regarding the occurrence records of alien plant species included in the database was extracted from 1174 published documents, i.e., 980 articles, 150 books, 29 PhD theses, six research reports, six conferences proceedings, and three herbarium data (see Suppl. material 3: Appendix S3 for a detailed list). The occurrence records were checked for taxonomic and geographic quality. The records that could not be georeferenced (e.g., occurrences assigned only to mountain ranges, historical provinces, and hydrographic basins) or records with unspecified taxa within genera, were not included in the current version of database. The species taxonomy considered in the present paper is based on GBIF Backbone Taxonomy (GBIF Secretariat 2021).

For each species included in our database, we added information on taxonomy, the native range and the pathways of introduction according to Sirbu and Oprea (2011a). The introduction pathways were standardized based on the main categories described in the Convention on Biological Diversity (CBD 2014): release in nature, escape from confinement, transport-contaminant, transport-stowaway, corridor, and unaided. Each main category includes several sub-categories. For example, the intentional release of alien species in nature can be due to various reasons such as erosion control and dune stabilization or landscape/flora/fauna "improvement" in the wild. The categories used in this study are detailed in Table 1. Finally, we used a chord diagram (Gu et al. 2014; Turbelin et al. 2017) to visualize the introduction pathways and geographical origin of the alien plant species included in the database.

To aggregate IAP species occurrence records, we followed the approach established by Cogălniceanu et al. (2013). Valid occurrence records were aggregated at a Universal Traverse Mercator (EPSG 9807) spatial resolution of 25 km^2 (UTM 5 × 5 km) using the UTM index of localities and Google Maps/Google Earth (Alphabet Inc., Santa Clara CA). Georeferenced data points were transferred to ArcGIS 10.3 (ESRI, Redlands CA) and visually inspected for errors.

Spatial patterns in IAP species occurrences were analyzed using spatial autocorrelation of species records per 5 × 5 km grid cell at the national level. We used Global Moran's I test to evaluate the overall spatial pattern of occurrences reported from Romania (Fortin and Dale 2005). The test indicates if reported occurrences at grid cell level are significantly clustered ($Z > 0$), to random ($Z = 0$) and dispersed ($Z < 0$) across Romania. To assess the local patterns of sampling bias, we used the Getis Ord Gi* spatial statistic. This analysis identifies clusters of occurrence records with values numerically higher than expected by chance within a specified searching distance (Ord and Getis 1995). The distance threshold for the aggregation patterns was set up to 7100 m to include the neighboring eight grid cells for each UTM grid of interest (Cogălniceanu

Table 1. List of abbreviations used to describe the geographical origins of the alien plant species and their pathways of introduction.

Acronym	Description of acronym
Geographical origins	
A+P	Asia + Pacific
E	Europe
M	Mediterranean
A N+C	America (North + Central)
A S	America (South)
T	Tropics
A	Americas (North + Central + South)
O	Other regions and/or unknown origin
Pathways of introduction	
RE_eros	RELEASE IN NATURE: Erosion control/ dune stabilization (windbreaks, hedges, …)
RE_land	RELEASE IN NATURE: Landscape/flora/fauna “improvement” in the wild
RE_othr	RELEASE IN NATURE: Release in nature for use (other than above, e.g., fur, transport, medical use), or other intentional release
ES_agri	ESCAPE FROM CONFINEMENT: Agriculture (including Biofuel feedstocks)
ES_fore	ESCAPE FROM CONFINEMENT: Forestry (including afforestation or reforestation)
ES_hort	ESCAPE FROM CONFINEMENT: Horticulture, Ornamental purpose other than horticulture
ES_faci	ESCAPE FROM CONFINEMENT: Pet/aquarium/terrarium species (including live food for such species), Botanical Garden/zoo/aquaria (excluding domestic aquaria), Research and ex situ breeding (in facilities)
ES_othr	ESCAPE FROM CONFINEMENT: Other escape from confinement
TR_habi	TRANSPORT CONTAMINANT: Transportation of habitat material (soil, vegetation, …)
TR_seed	TRANSPORT - CONTAMINANT: Seed contaminant
TR_mult	TRANSPORT - STOWAWAY: Vehicles (car, train, …), Ship/boat ballast water or other means of transport
UN_intr	UNAIDED: Interconnected waterways/basins/seas
UN_natu	UNAIDED: Natural dispersal across borders of invasive alien species that have been introduced through pathways 1 to 5

et al. 2013). The Getis Ord Gi* test returns a Z-score for every cell, which, depending on the level of aggregation, describes spatial clusters of high or low sampling effort. We identified clusters of grid cells where the sampling effort was significantly higher (hot-spots of occurrence, GiZScore > 1.96) or lower (cold spots of occurrence, GiZScore < 1.96). IAP species richness was mapped at a spatial resolution of 50 × 50 km UTM grid cells. Aggregating species richness at a coarser resolution reduced the potential bias in sampling effort and allowed for a better understanding and visualization of regional patterns (Graham and Hijmans 2006).

The altitudinal distribution of each species was assessed by extracting the range and mean altitude per grid cell from the SRTM digital topographic database (Jarvis et al. 2008) using ArcGIS Desktop Zonal Statistics geoprocessing tool. Due to the size of grid cell (25 km^2), the altitudinal distribution of a given record might be over- or underestimated. Grid cells intersecting the Romanian border were excluded from the analysis.

The data underpinning the analysis reported in this paper are deposited at GBIF, the Global Biodiversity Information Facility, and are available at https://doi.org/10.15468/gg846v.

Results

Distribution and taxonomy of invasive and potentially invasive alien plant species in Romania

Following the extensive literature review, we identified 102 alien plant species to be included in the invasive or potentially invasive categories, as described in the Methods section (invasive, naturalised, casual cf. Richardson et al. 2000; Pyšek et al. 2004; Anastasiu and Negrean 2009; Sirbu and Oprea 2011b). The rate of accumulation of IAP species occurrence records shows a slow increase between 1778 and 1940s, with peaks in 1866 (29 occurrences) and 1898 (25 occurrences), followed by a steady increase with a maximum in 2009 (82 occurrences) (Fig. 1). Regarding the new IAP species discovered in Romania, we observed a maximum of nine new plant species reported in 1816, followed by seven new plant species reported in 1866 (Fig. 2). In the 20th century, the data in the literature indicates a maximum of four new alien species recorded per year in the 1950s and one species per year in the 2000s.

The documented IAP species cover 41 families, with most species belonging to Asteraceae (23%), followed by Amaranthaceae (12%), Poaceae (6%) and Fabaceae (5% of species) families. Eight species in our database had more than 1000 occurrence records each (i.e., *Erigeron canadensis*, *Erigeron annuus* subsp. *annuus*, *Ambrosia artemisiifolia*, *Amaranthus retroflexus*, *Xanthium orientale* subsp. *italicum*, *Robinia pseudoacacia*, *Galinsoga parviflora*, and *Xanthium spinosum*), while eight species had less than ten occurrence records (i.e., *Verbesina encelioides*, *Grindelia squarrosa*, *Ambrosia tenuifolia* – previously

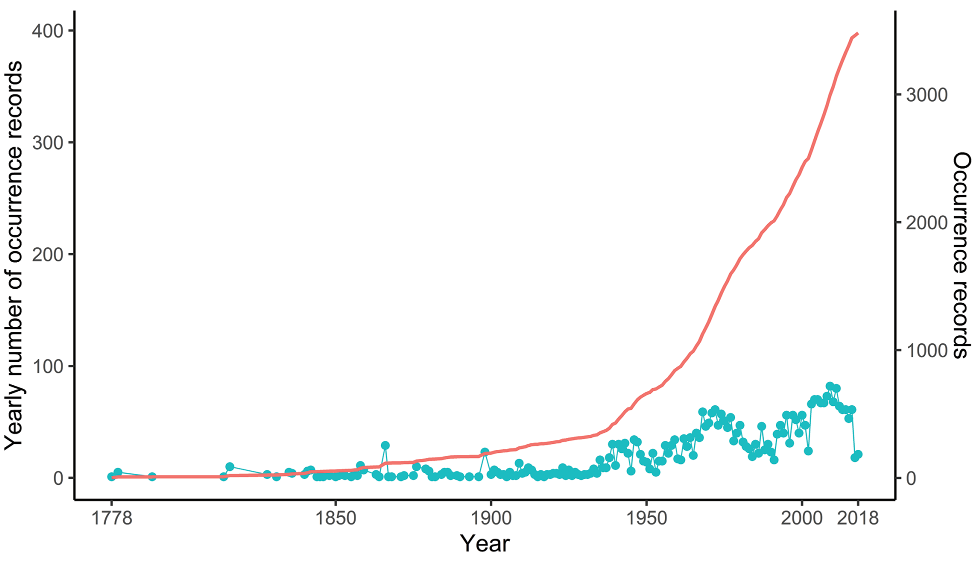

Figure 1. Yearly number of invasive and potentially invasive alien plant species occurrence records reported from Romania (blue) and accumulation of occurrence records (red).

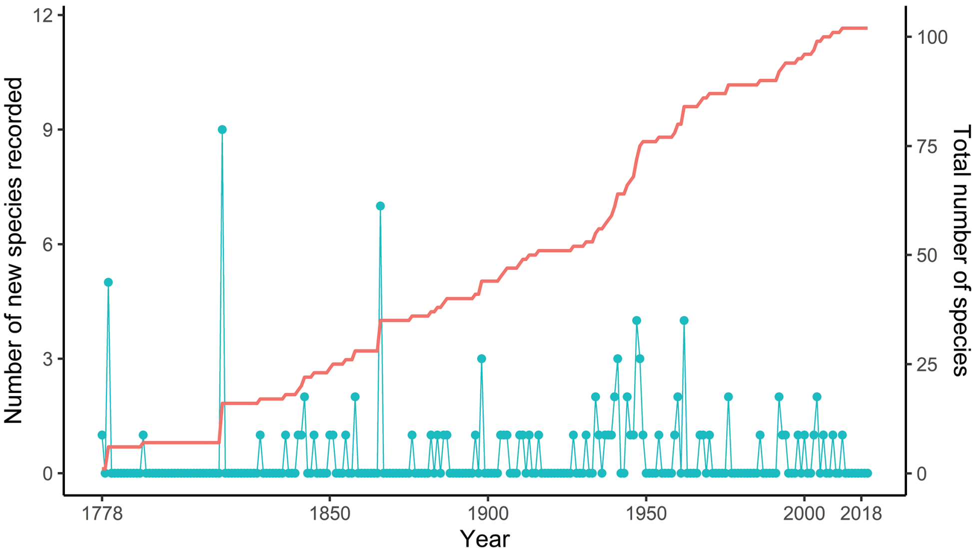

Figure 2. Number of new invasive and potentially invasive alien plant species reported during the 1778–2018 period from Romania (blue) and accumulation of species (red).

erroneously reported as *Ambrosia psilostachya*, according to Karrer et al. (2021), *Heracleum sosnowskyi*, *Heracleum mantegazzianum*, *Cabomba caroliniana*, *Myriophyllum aquaticum*, *Rhaponticum repens*). Most occurrence records were registered for species belonging to the Asteraceae family (see Suppl. material 1: Appendix S1 for a detailed list).

Furthermore, eight of the IAP species whose presence was recorded in Romania up to (and including) 2018, are listed as invasive alien species of Union concern according to the Regulation (EU) No. 1143/2014 of the European Parliament and of the Council (i.e., *Ailanthus altissima*, *Asclepias syriaca*, *Cabomba caroliniana*, *Elodea nuttallii*, *Heracleum sosnowskyi*, *Humulus japonicus*, *Impatiens glandulifera* and *Myriophyllum aquaticum*). *Cabomba caroliniana* and *Myriophyllum aquaticum* were reported from one location, a Nature 2000 site, the thermal lake Pețea in Bihor County (the western part of Romania), currently without water. Only one record of *Heracleum sosnowskyi* in the wild was available from the literature, but recent field work efforts confirmed the presence of the species.

The current version of the database includes 42776 occurrence records belonging to 102 taxa. The altitudinal range of IAP species recorded in Romania (average altitude in 25 km^2 grid) varied between 0 and 2288 m. Only eight IAP species (e.g., *Bidens frondosa*, *Erigeron canadensis*, *Erigeron annuus* subsp. *annuus*, *Galinsoga quadriradiata*, *Impatiens parviflora*, *Juncus tenuis*, *Robinia pseudoacacia* and *Rudbeckia laciniata*) occur in grid cells with average altitude above 2000 m, while most species were recorded in grid cells with average altitude between 0 and 500 m (Fig. 3). The number of IAP species decreased with increasing altitude, the correlation being negative and statistically significant (r = -0.099, p <.000).

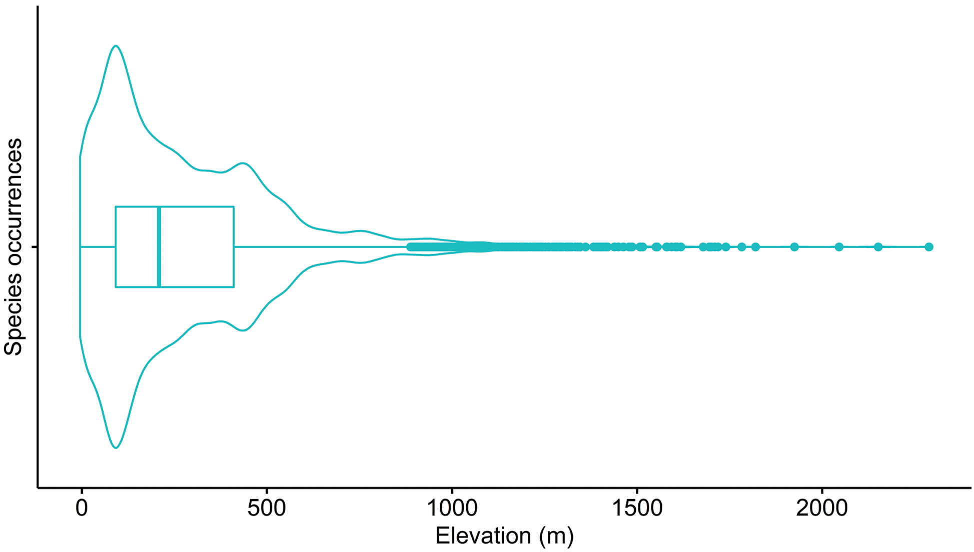

Figure 3. Altitudinal range of IAP species recorded in Romania (mean altitude of UTM 5 × 5 km grid cell). Box = interquartile range, horizontal line = median, whiskers = 1.5 × interquartile range, points = outliers, the vertical width of violin = density of the data.

Spatial patterns in invasive and potentially invasive alien plant species occurrences

Almost half (47%, i.e., 4764 grid cells) of the 9978 UTM 5 × 5 km grid cells covering the Romanian territory include reports of IAP species sightings. Global Moran's I test revealed a clustered pattern in the number of IAP species ($Z = 30.50$, $p < 0.001$) and of species occurrences ($Z > 1.96$, $p < 0.05$) per UTM 5 × 5 grid cell, thus suggesting a strong bias in the sampling effort at national level.

Results of the Getis Ord Gi* spatial statistic revealed three hotspots of recorded IAP species. We observed a strong clustering of records in cities and surroundings (e.g., Iasi, Sibiu, Bucharest, Cluj-Napoca, Zalau, Constanta and Galati). Among these hotspots, the highest sampling effort was recorded in Iasi city and its surrounding area (mean $Z = 24.17$), followed by Bucharest (mean $Z = 12.71$) and Sibiu (mean $Z = 12.40$) (Fig. 4). Additionally, there are several smaller hotspots in Salaj County (in the northwestern part of Romania), in Vaslui and Galati counties (the eastern part of Romania), and around the cities of Cluj-Napoca (in the western part of Romania) and Constanta (southeastern Romania).

Species richness aggregated at a 5 × 5 km grid, ranged from 2 to 59 species. The highest number of IAP species was recorded around cities, namely Bucharest, Iasi, and Sibiu (59 species per grid cell), followed by Cluj-Napoca (55 species per grid cell), Constanta and Sulina (53 species per grid cell) (Fig. 5). Most of the grid cells with high IAP species richness recorded are concentrated in particular regions of Romania i.e., the eastern part (e.g., Iasi, Vaslui, Galati and Neamt counties), the center (e.g., Sibiu County), northwest (e.g., Salaj County), and the southern part of Romania (Bucha-

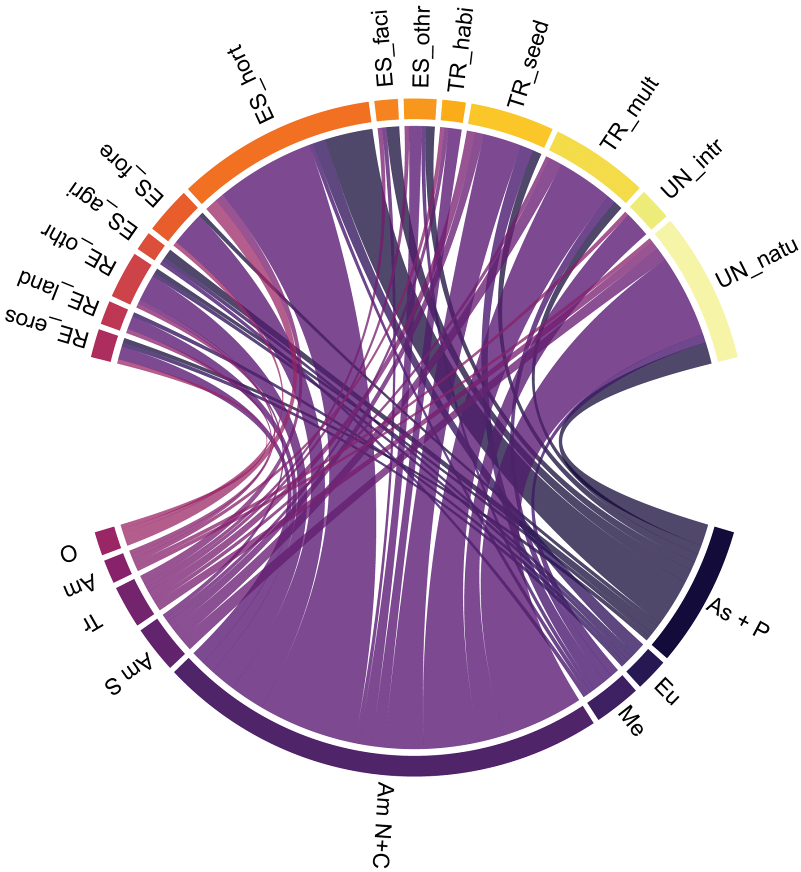

Figure 4. Hotspots of invasive and potentially invasive alien plant species sampling in Romania (in red). The p-value was < 0.05 when Z scores took values between 1.96 and 33.87, suggesting a highly clustered pattern in the number of IAP species occurrences per UTM 5 × 5 km grid cell.

rest), suggesting a more intensive sampling of IAP species when compared to other regions. Grid cells with low richness values are mostly distributed in the southern and western parts of the country, reflecting an under sampling of IAP species. When represented at a lower spatial resolution (50 × 50 km), IAP species richness ranged from 3 to 70 species per grid cell (Fig. 6). The same patterns can be observed on the map, lower IAP species richness in the southern and western parts of the country and higher in the eastern and central parts of Romania.

Geographical origins and pathways of introduction

The analysis on the pathways of introduction and the geographical origins of the IAP species is illustrated in Fig. 7 (see Table 1 for abbreviations). For example, the introduction pathway Escape from confinement – Forestry (ES_fore) contributed to the

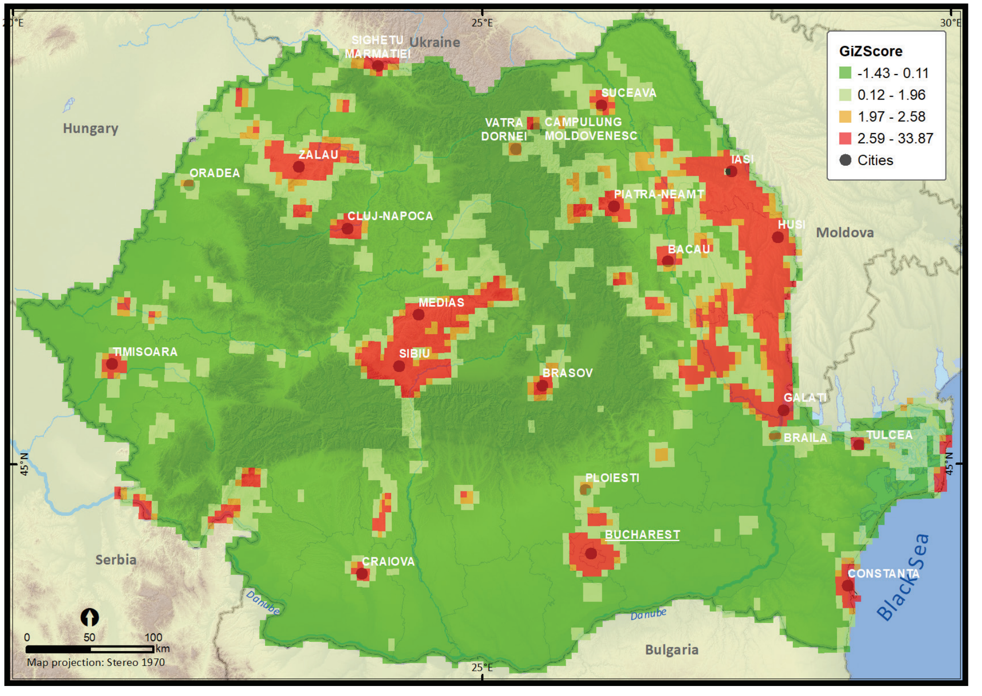

Figure 5. Invasive and potentially invasive alien plant species richness in Romania (5 × 5 km grid resolution).

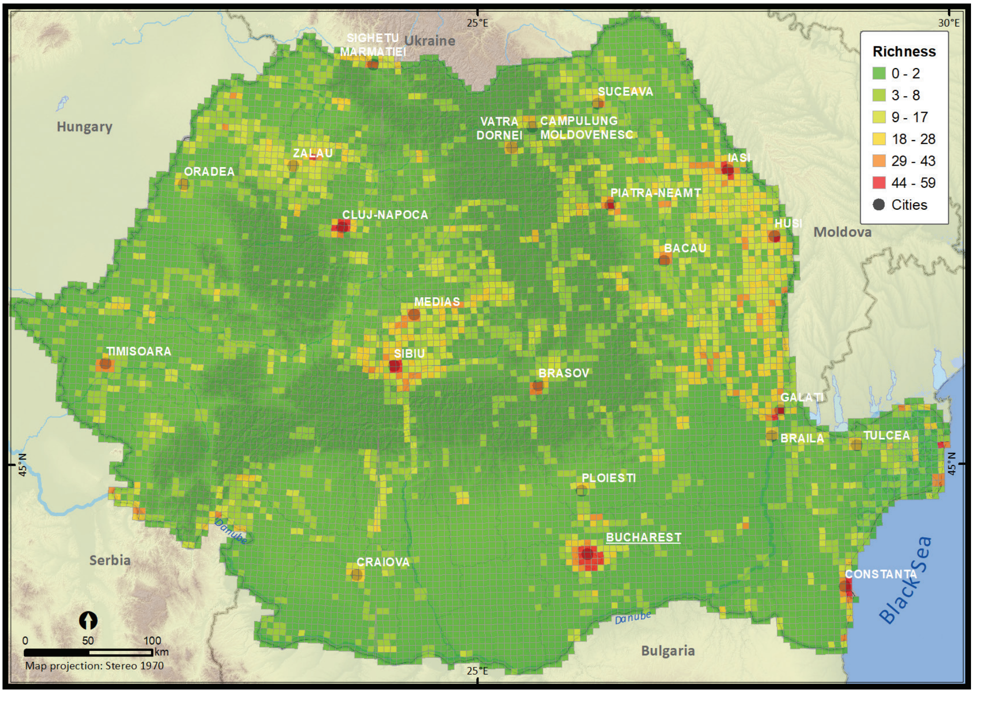

Figure 6. Invasive and potentially invasive alien plant species richness in Romania (50 × 50 km grid resolution).

introduction of ten species in Romania, while the pathway Escape from confinement – Agriculture (ES_agri) is responsible for only four species (n = 102). The majority of the species in our database (62.7% species) had one pathway of introduction documented, while for two species, *Ailanthus altissima* (Mill.) Swingle, and, *Acer negundo* L., we identified six and seven pathways respectively.

The data shows that the geographical origin of most IAP species included in our database is in Northern and Central America (56.1% of the species), followed by Asia and Pacific (17.3% of the species) (Fig. 7). Most species (24.9% of the recorded species) were introduced intentionally for horticulture or ornamental purposes (ES_hort in Fig. 7). Examples are *Prunus cerasifera*, used in horticulture, and the species *Ailanthus altissima*, *Amorpha fruticosa* and *Fraxinus americana* used for ornamental purposes. Out of the 102 recorded IAP species, 32 species entered Romania by natural dispersal across borders (UN_natu), after being introduced to Europe through various other ways, mainly from North and Central America. Examples of plants that dispersed naturally are *Symphyotrichum ciliatum* and *Veronica persica.* Other important pathways of introduction are transportation as stowaway (TR_mult) and seed contaminant (TR_seed), with 12.1%, and 10.4% of species being introduced through these pathways respectively.

Discussion

In this article we advance an important step towards establishing a comprehensive national database of invasive and potentially invasive alien plant species occurrences in Romania along with their distribution and pathways of introduction. The distribution of species was compiled from documents published between 1778 and 2018. We included in the database the records that fulfilled taxonomic and location quality criteria, and provide an analysis of the accumulation rate of species and occurrences, a spatial analysis of alien species diversity and a summary of introduction pathways.

The accumulation rate of invasive and potentially invasive alien plant species occurrences showed a steady increase after the 1950s, peaking in three time periods (1968–1974, 1995–2000, and 2009). This pattern is likely due to local initiatives focused on biological invasions, that led to the publishing of scientific papers and books, improving the knowledge of alien plants in Romania (Mititelu and Barabaș 1972; Negrean 1972; Ciocârlan et al. 1997; Coroi and Coroi 1997; Costea 1997; Ștefan and Oprea 1997; Anastasiu et al. 2009). However, since 1955, the number of occurrences reported has more than doubled and it is unlikely it will decrease in the future (Seebens et al. 2017, 2021). A similar rapidly increasing tendency after the 1950s has been reported by Nikolić et al. (2013) for Croatia. Peaks in the number of new recorded species have also been reported by other studies, with some variation in the time moment of the peak, for example the peak reported to take place during the 1940s and 1960s in eastern Africa (Witt et al. 2018).

The number of occurrences varies among species. Asteraceae with 26 species represented the most dominant family in the IAP species list. Furthermore, the majority of

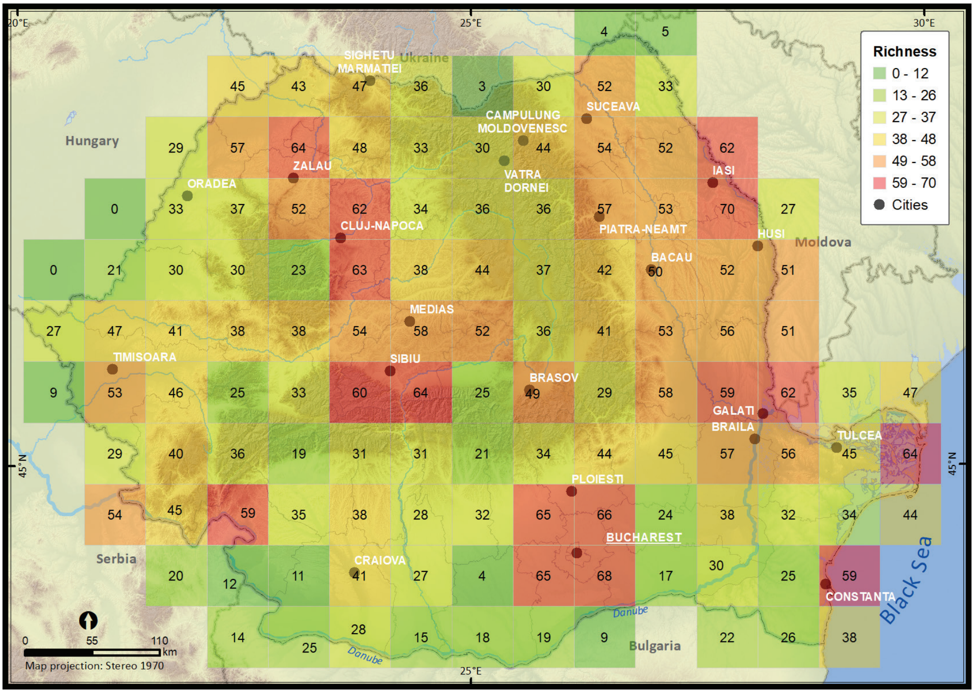

Figure 7. Proportion of invasive and potentially invasive alien plant species' introductions by pathway and geographic origins (see Table 1 for abbreviations).

the reported species are able to colonize disturbed and/or urbanized ecosystems in their native range (see Suppl. material 1: Appendix S1). The horseweed, *Erigeron canadensis*, is the species with the largest number of reported occurrences (3717 reported occurrences) at national level, having an altitudinal range varying between 3 and 2153 m. Also frequently recorded are the common ragweed, *Ambrosia artemisiifolia*, and the annual fleabane, *Erigeron annuus* subsp. *annuus* (more than 2000 occurrence records each). These species have a wide altitudinal range (between 0 and 1252 m the former, and between 0 and 2288 m the latter), inhabiting both lowlands and highlands. However, most IAP species from our database have been recorded between 0 and 500 m altitude (see Suppl. material 2: Appendix S2).

The number of newly reported species varies greatly among years (see Fig. 2), and, at least in the case of species reported in the 19th century, are linked to the publishing of monographical works. For example, the high number of new IAP species reported in 1816 is due to the works of Baumgarten (1816), who devoted his time to botanical research and published four volumes on Transylvanian flora. In 1866, seven new IAP species were added to the recorded flora of Transylvania by two other botanists (Fuss 1866; Schur 1866).

Most IAP species recorded in Romania originate in North and Central America (56.1%), followed by Asia and the Pacific (17.3%). Intentional introductions contributed only slightly more (52.0%) than unintentional introductions (48.0%) to the presence of the IAP species in Romanian flora. Findings are in contrast with observations made by Lambdon et al. (2008) for Europe, where he pointed out that intentional introductions prevail over unintentional introductions. However, our findings are in agreement with the study by Hulme et al. (2008) with respect to the fact that horticulture and the use of alien plant species for ornamental purposes is the main pathway of introduction for the largest and most diverse group of species.

Unintentional introductions by transportation of plants as contaminants and stowaways play an important role in Romania. Globalization and economic development facilitated the local, regional, and global transfers of invasive alien species (Hulme 2009). For example, Lemke et al. (2019) demonstrated that the traffic volume significantly affected dispersal distances and the lateral deposition of seeds of *Ambrosia artemisiifolia* on the roadsides in Germany. The same IAP species was repeatedly reported in Romania, probably because it is conspicuous and highly allergenic. The important role of the high traffic roads in the dispersal of IAP species (Mortensen et al. 2009; Rauschert et al. 2017) is evident in Romania, as most of the 5 × 5 km grid cells in which IAP species were recorded are crossed by, or have roads with, high traffic volumes nearby (e.g., European routes E85, E81 and E60).

The horticulture industry, notably the ornamental horticulture, is also considered an important pathway for introducing and dispersing alien species (Drew et al. 2010). Botanical gardens and dendrological parks can also contribute to introducing and spreading invasive alien species, especially in case of defective management and design (Reichard and White 2001; Simberloff 2010). Our results revealed hotspots of IAP species near major academic and research facilities, for example, Iasi (eastern Romania), Sibiu (central Romania), Bucharest (southern Romania), and Timisoara (western Romania) (Fig. 4). In these areas, the higher-than-expected number of IAP species occurrences per grid cell can be explained by the presence of major academic and research facilities with biology/botany departments and large botanical gardens and dendrological parks. Similar biased sampling effort explained by the work of local researchers is Salaj County (Zalau, center of Romania).

Our analysis suggests data collection was conducted opportunistically rather than systematically, an issue noticed before in Romania (Cogălniceanu et al. 2013) and in other parts of the world (Hortal et al. 2007). To better capture the IAP species distribution in Romania and avoid the botanist effect on data (Pautasso and McKinney 2007), researchers should start sampling more intensively areas away from major academic and research facilities, and outside of popular protected areas.

Conclusions

The present study provides a systematic analysis of invasive and potentially invasive plant species in Romania. Our findings based on the review of existing literature, show the presence of 102 IAP species pertaining to 41 families. The number of occurrences has increased steadily after 1950s, with new species being continuously introduced. Species originating mainly in North and Central America have been introduced almost equally through intentional and unintentional pathways. Mapping the species occurrences has revealed several hotspots of IAP species which concentrate in urban areas and their surroundings. The data collected in this study is made available through an open-access spatial database. We suggest that this database is maintained, regularly updated and used to build upon e.g., include all alien plants naturalized in Romanian flora and also other taxa. We consider it a valuable tool in biological invasions management at national level, as well as regionally, and for setting conservation priorities for species and sites, but also for further studies on impacts. In agreement with Regulation (EU) No. 1143/ 2014 (EU Regulation 2014), data about the distribution and pathways of introduction is necessary in order to establish a surveillance system.

Ahrends et al. (2011) highlighted how resources for descriptive taxonomy and biodiversity inventories have substantially declined in the last decades. Limited financial and logistic resources for field botany and taxonomy translated into a decrease in quality of biodiversity data, emphasizing that the funds oriented towards biodiversity research and conservation are rather insufficient or inefficiently spent. Future inventory activities must be oriented predominantly towards those counties/regions for which the data in the published literature is lacking.

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Supplementary material 1

Appendix S1. List of invasive and potentially invasive alien plant species in Romania

Authors: Culita Sirbu, Iulia V. Miu, Athanasios A. Gavrilidis, Simona R. Gradinaru, Iulian M. Niculae, Cristina Preda, Adrian Oprea, Mihaela Urziceanu, Petronela Camen-Comanescu, Eugenia Nagoda, Ioana M. Sirbu, Daniyar Memedemin, Paulina Anastasiu

Data type: (docx. file)

Explanation note: List of invasive and potentially invasive alien plant species in Romania (* denotes an invasive alien species of Union concern pursuant to Regulation (EU) No 1143/2014 of the European Parliament and of the Council).

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Link: https://doi.org/10.3897/neobiota.75.84684.suppl1

Supplementary material 2

Appendix S2. Altitudinal range of invasive and potentially invasive alien plant species recorded in Romania

Authors: Culita Sirbu, Iulia V. Miu, Athanasios A. Gavrilidis, Simona R. Gradinaru, Iulian M. Niculae, Cristina Preda, Adrian Oprea, Mihaela Urziceanu, Petronela Camen-Comanescu, Eugenia Nagoda, Ioana M. Sirbu, Daniyar Memedemin, Paulina Anastasiu

Data type: (docx. file)

Explanation note: Appendix S2. Altitudinal range of invasive and potentially invasive alien plant species recorded in Romania (mean altitude of UTM 5 × 5 km grid cell). Box = interquartile range, horizontal line = median, whiskers = 1.5 × interquartile range, points = outliers); The species ID corresponds to the IDs provided in Suppl. material 1: Appendix S1.

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Link: https://doi.org/10.3897/neobiota.75.84684.suppl2

Supplementary material 3

Appendix S3. Publications used to compile distribution of alien plant species in Romania.

Authors: Culita Sirbu, Iulia V. Miu, Athanasios A. Gavrilidis, Simona R. Gradinaru, Iulian M. Niculae, Cristina Preda, Adrian Oprea, Mihaela Urziceanu, Petronela Camen-Comanescu, Eugenia Nagoda, Ioana M. Sirbu, Daniyar Memedemin, Paulina Anastasiu

Data type: (docx. file)

Explanation note: Appendix S3. Publications used to compile distribution of alien plant species in Romania.

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Link: https://doi.org/10.3897/neobiota.75.84684.suppl3