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ALIEN FLORAS AND FAUNAS 37

Alien plant taxa in ecosystems of Armenia and invasion risk assessment

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Abstract Armenia is a small mountainous country that has been at the crossroads of numerous human migrations and trade for millennia. The number of alien plant species has increased exponentially over the last century. The article analyses 113 plant alien species, which are recorded in natural and semi-natural habitats (62 casual, 25 naturalised and 26 invasive). Most species are casual phanerophytes, while naturalised and invasive alien species are predominantly therophytes. The floristic regions richest in alien species in Armenia are Yerevan, Idjevan and Lori. The three primary regions of origin are North America, East Asia and Europe, and the main introduction pathways are ornamental, natural dispersal and forestry. Casual species are primarily found in urban and semi-urban habitats, whereas naturalised and invasive species thrive mainly in natural areas (i.e., forests, shrublands and wetlands). A weed risk assessment conducted on the alien species indicates that all naturalised species and nearly half of the casual species have the potential to invade the country.

Keywords Alien flora · Invasive plant species · Armenia · Risk assessment

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Introduction

The introduction of species by humans outside their native range is occurring at an unprecedented rate of approximately 200 per year (Roy et al. 2023). These species may cause irreversible changes in ecosystem properties (Vilà et al. 2011) and are among the leading causes of local extinctions (Bacher et al. 2023). The process of invasion by alien plants is significantly more complex in mountainous regions than in lowland areas. On one hand, terrain harshness and climatic conditions act as barriers to species dispersal and establishment. On the other hand, infrastructure development in mountain areas (e.g., transport networks, resorts, tourism) increases disturbance and connectivity, facilitating the invasion of alien plants (Barros et al. 2025). Moreover, the high diversity of natural and climatic conditions resulting from the elevation gradient, in the context of climate and land-use changes, makes these ecosystems highly vulnerable to plant invasions (Iseli et al. 2023). It is now well established that mountain ecosystems are generally less invaded than surrounding lowland ecosystems, and many mountains have few invasive plant species (McDougall et al. 2011). However, mountains may only be less invaded because most past alien plant introductions happened in the lowlands, and few potential invaders of mountain ecosystems managed to spread along steep climate gradients to high elevations (Alexander et al. 2011). Indeed, research in recent years shows that future plant invasions in mountains will increase under climate change and increased anthropogenic pressure (Alexander et al. 2016; Petitpierre et al. 2016; Seebens et al. 2023). Therefore, studying the alien flora in mountainous regions, including documentation of their traits, origin, pathways of introduction and habitats of occurrence, is of interest to scientists and practitioners alike (Joshi et al. 2022; Schwindt et al. 2023).

Armenia is a small country located in the South Caucasus, bordering Georgia, Azerbaijan, Türkiye and Iran. It is far from sea basins, with an area of less than 30,000 km^2. In Armenia, all the major ecosystems of the entire Caucasus are present, apart from humid subtropical ecosystems (Fayvush 2023). Thus, it offers a wide range of ecological conditions that may favour the establishment of species with diverse origins. Moreover, Armenia is the birthplace of one of the most ancient civilisations and has been at the crossroads of the world for many millennia, with one route of the 'Great Silk Road' passing directly through the country. Consequently, numerous plant species from Asia and Europe have been historically introduced, either voluntarily or involuntarily. These species are predominantly cultivated in orchards and have wild relatives in Armenia, e.g., *Persica, Prunus, Pyrus, Malus* and *Rubus*. Many of these species are termed archaeophytes, introduced before ca 1500, both accidentally and deliberately (Pyšek et al. 2004). For example, the homeland of apricot (*Prunus armeniaca*) originates in Northern China (Weisskopf and Fuller 2014; Liu et al. 2019; Bourguiba et al. 2020); it appeared in Armenia at least 5000 years ago (Morikian 1983) and now has numerous local and semi-wild varieties derived from cultivation.

Until the early twentieth century, the introduction of plants in Armenia was largely untargeted and often accidental. In the 1930s, when the Yerevan Botanical Garden and the Institute of Botany were established, scientifically driven initiatives were launched to introduce new plant species, primarily for landscaping purposes. The Yerevan Botanical Garden (with its branches in the cities of Vanadzor and Sevan) and four arboretums were established to conduct research on the acclimatisation of introduced species in various natural and climatic zones. By 1985, more than 1,500 predominantly woody plant species had been tested (Annotated Catalog 1985). However, many of these species did not acclimatise to the new conditions and were removed from the collections (Vardanyan et al. 2024). Another important group of alien species in Armenia comprises species that were widely used in landscaping across the country, e.g., for creating artificial green spaces in urbanised areas and in shelterbelts along highways and railways (Mulkijanyan and Mkrtchyan 1953; Davidova 1959; Makhatadze 1959). Some of these species 'escaped' from cultivation, becoming naturalised and even invasive (Fayvush and Tamanyan 2014). Some have also been used in afforestation of new areas, particularly in forest plantations on exposed soils after the recession of Lake Sevan (Makhatadze et al. 1957; Makhatadze and Khurshudyan 1962). In addition, approximately 50 species have entered Armenia through other pathways and some are recorded in natural and anthropogenically disturbed habitats (Fayvush et al. 2022, 2024).

The study of the alien flora of Armenia began in the mid-1990s, but efforts have intensified over the past 25 years. Currently, we estimate that there are about 1255 alien species in the country (Vardanyan et al. 2024). The vast majority of these grow exclusively in botanical gardens and arboretums. Around 400 are recorded in the Global Register of Introduced and Invasive Species (GRIIS) (Fayvush et al. 2020a). However, apart from species that have already spread widely into natural ecosystems and exhibit the characteristics of invasive species, GRIIS includes introduced plant species known to be invasive in other regions of the world but not yet recorded in the natural ecosystems of Armenia. Therefore, there is a need to list alien species currently found in the wild and to identify those with the highest risk of becoming invasive.

This study aims to extract from the list of all alien plant species those that occur in the wild, in natural and semi-natural habitats of Armenia (i.e., outside of cultivation, botanical gardens and parks, etc.). Our study focus on neophytes, alien species introduced after ca 1500, both accidentally and deliberately, regardless of invasion status (Pyšek et al. 2004). Specifically, we provide information on: (1) plant taxonomic composition, life form, life cycle and growth form; (2) species origin, introduction pathways and time of introduction; and (3) invaded habitats and ecoregions in the country. We also applied a weed risk assessment (WRA) scheme to identify potentially invasive species.

Materials and methods

Study area

Armenia is a South Caucasian republic, bordering with Georgia, Azerbaijan, Turkey, and Iran. It is a landlocked country with a total area of 29,740 km^2, at a distance of about 145 km from the Black Sea, and 175 km from the Caspian Sea. It lies between 38°50′ and 41°18′ of northern latitude and between 43°27′ and 46°37′ eastern longitude, and measures 400 km along its main axis (north–west to south–east). Armenia is generally a mountainous country, having its lowest point of 375 m above sea level and culminating at 4095 m with an average altitude of 1850 m (Fig. 1; Fayvush 2023).

Armenia possesses a wide range of climatic zones, with six basic climate types—from dry subtropical to alpine. The average annual temperature ranges from −8 °C in high-altitude mountainous regions (over 2500 m a.s.l.) to 12–14 °C in low-lying valleys. The diversity of landscapes and climatic belts significantly influences Armenia's diverse vegetation. The lower mountain belt (480–1200 m) is covered by semi-desert formations and gypsophilous or halophilous vegetation. The middle and upper mountain belts (1200–2200 m) are characterised by various types of steppe and forest vegetation, including meadow-steppes, shrub steppes and thorny cushion ('tragacanth') vegetation. The altitudinal range of the forest belt varies from 500 to 2200 m depending on the region and may extend to 2400 m. The subalpine and alpine belts (2200–4000 m) are covered by meadows and carpets (Magakyan 1941; Takhtadjan 1941; Fayvush and Aleksanyan 2016a, b; Fayvush 2023).

Armenia lies at the intersection of two phytogeographical subkingdoms: Boreal (Euro-Siberian) and Ancient Mediterranean (Takhtadjan 1986).

The ancient history of the formation of the flora and vegetation of Armenia, the diversity of natural conditions, the impact of various biotic and abiotic factors on them, the different geological history of individual parts of the republic have led to a high degree of heterogeneity of its flora. In 1954, in preparation for the publication of the first volume of the Flora of Armenia, Takhtajan divided the entire territory of the republic into 12 floristic regions, reflecting the characteristics of their floristic composition and main ecosystems, and provided a corresponding map-scheme.

Based on numerous literature and herbarium data, as well as long-term observations in nature, we made some adjustments to the floristic zoning of Armenia by A. L. Takhtajan (Tamanyan and Fayvush 2010) and in this work we use this updated scheme to indicate the distribution of plant species and ecosystems throughout the republic. We accept 12 floristic regions within the following boundaries (Fig. 2a).

From an administrative standpoint, Armenia is divided into 10 regions (provinces), with the city of Yerevan as a separate administrative unit (Fig. 2b).

Data gathering

Our primary sources of information include numerous field surveys conducted over the last 30 years, during which we recorded and collected all species. Specimens are housed in the herbarium of the Institute of Botany after A. Takhtadjyan of the National Academy of Sciences of the Republic of Armenia (ERE), and partially in the herbarium of the Naturhistorisches Museum Wien (W). Furthermore, the most important sources of information on the time and pathways of introduction into the republic are the ERE and Yerevan State University (ERCB) herbaria, as well as the multi-volume edition of 'Flora of Armenia' (1954–2010) and some publications on the first records of plant species in the republic (e.g. Gabrielyan and Tamanyan 1985). Currently, the botanists of the A. Takhtajyan Institute of Botany of the National Academy of Sciences of the Republic of Armenia strive to collect and contribute new floristic data for Armenia. For example, Dr. E. Vitek (Natural History Museum Vienna)

Fig. 1 Location of Armenia in the Caucasian Ecoregion

during the period 2002–2015 annually organized targeted expeditions to different regions of Armenia and Nagorno-Karabakh (Vitek et al. 2015: Figure in Appendix 2, Supplementary materials). Herbarium material collected during these expeditions is currently stored in the herbariums of the Institute of Botany of the National Academy of Sciences of the Republic of Armenia (ERE) and the Natural History Museum Vienna (W).

For the modern interpretation of the placement of species in families, we relied on the multi-volume publication "Flora of Armenia" (1954–2010), "Plants of the World Online" (Royal Botanical Gardens Kew—https://powo.science.kew.org), and Global Biodiversity Information Facility (GBIF; https://www.gbif.org) databases.

The native ranges of the alien plant species were primarily sourced from the GIDIAS database (Bacher et al. 2025), supplemented by additional records from the CABI Compendium (https://www.cabidigitallibrary.org/journal/cabicompendium) and the USDA PLANTS Database (https://plants.sc.egov.usda.gov) We classified the alien plant species into casual, naturalised or invasive. We adopted the terminology proposed by Richardson et al. (2000). 'Casual' refers to alien plants that may flourish and even reproduce occasionally in an area but do not form self-replacing populations. Naturalised plants are those alien plants

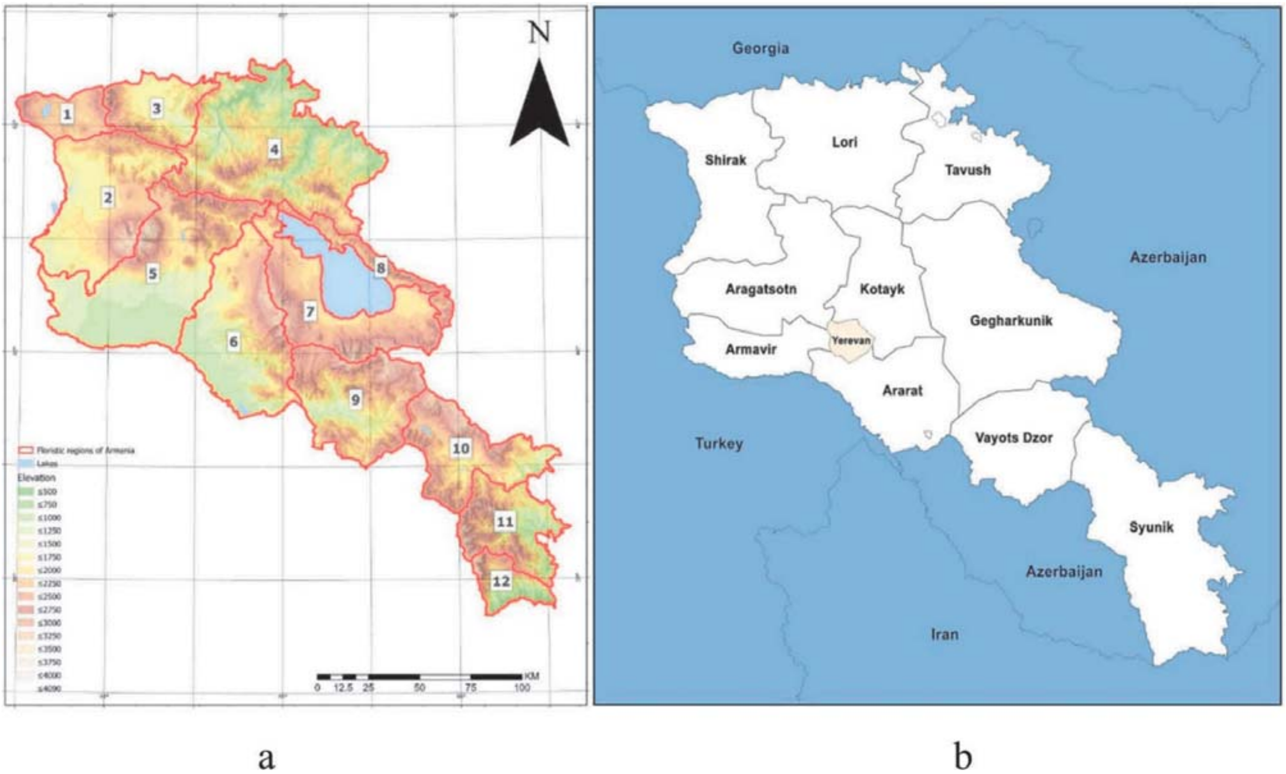

Fig. 2 Floristic and administrative divisions of Armenia. **a** Floristic regions: 1. Upper-Akhuryan, 2. Shirak, 3. Lori, 4. Idjevan, 5. Aparan, 6. Yerevan, 7. Sevan, 8. Areguni, 9. Darelegis, 10. North Zangezur, 11. South Zangezur, 12. Meghri. **b** Administrative regions

that reproduce consistently and sustain populations over many life cycles without direct intervention by humans. Invasive plants are naturalised plants that produce reproductive offspring, often in very large numbers, and spread considerable distances from parent plants. For each species, we recorded its life history traits (i.e., life form, growth form and life cycle), introduction pathways according to the CBD classification following Harrower et al. (2018), region of origin, habitats where the species is found according to the IPBES units of analysis used in the Assessment Report on Biodiversity and Ecosystem Services (Aidin and Obura 2019), and its time of introduction based on herbarium specimens and our expertise.

To assess the invasion risk of each alien species, we used the Australian Weed Risk Assessment (Gordon et al. 2008, 2010), which has been adapted to many other regions of the world to identify potential invasive species (Daehler and Carino 2000; Daehler et al. 2004; Křivánek and Pyšek 2006; Gassó et al. 2010; Singh and Priyadarshi 2014; Gordon et al. 2016; Vilizzi et al. 2022, 2024, 2025). The method involves answering 49 questions related to the bio-ecological characteristics of the assessed species. For each answer, the species is assigned a certain number of points. The total sum of all points characterises the degree of invasion risk for each species: A high score (>6) identifies a species likely to be of high risk (i.e. reject), a low score (<1) identifies a species of low risk (i.e. accept) and intermediate scores (1–6) indicate that the species requires further evaluation. The WRA score ranges from -14 (benign species) to 29 (maximum risk).

Results

Of the 113 alien species recorded in Armenia's ecosystems, 62 are classified as casual, 25 as naturalised and 26 as invasive (Appendix 1, Supplementary material). They belong to 47 plant families, with the most common being *Asteraceae, Rosaceae, Fabaceae, Poaceae* and *Caprifoliaceae* (Fig. 3). Over 50% of invasive species are *Asteraceae* (14 out of

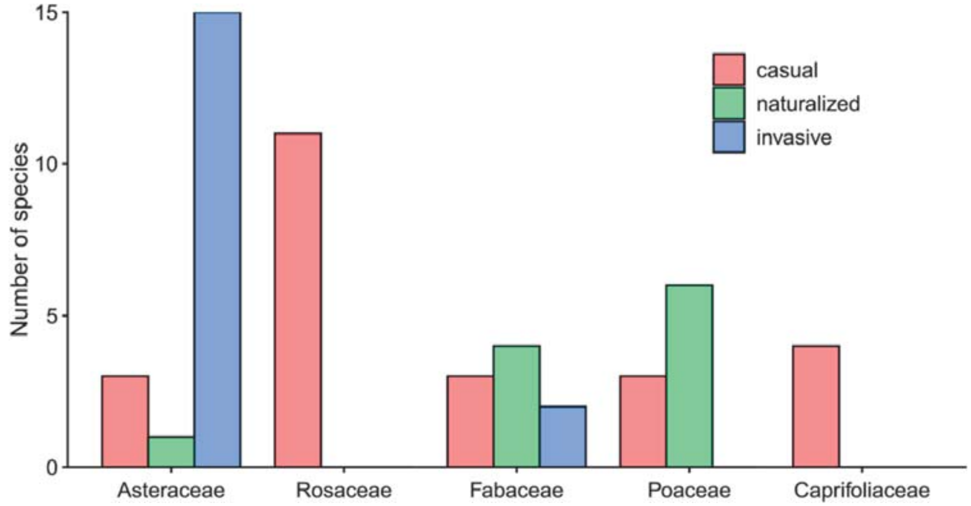

Fig. 3 Main taxonomic families of the alien flora of Armenia. We report families with more than four species

26 species). *Rosaceae* is the most common family among casual species with 12 species, while *Poaceae* and *Fabaceae* are the most frequent families among naturalised species.

Phanerophytes and therophytes are the most common life forms among the alien plants of Armenia (Table 1). Invasive and naturalised species are mostly herbs (72%), either therophytes or hemicryptophytes. Casual species are more frequently phanerophytes (69%).

Alien plant species have primarily been introduced as ornamental (61%) or forestry (17%) species (Table 2), although many have arrived in the country through their own dispersal mechanisms (30%). Casual alien species are mostly found in urban and semi-urban areas, whereas invasive species also occur in natural areas such as forests, shrublands and wetlands (Fig. 4).

The most common origins of alien species are North America and East Asia, with many casual species also native to the Mediterranean basin (Fig. 5). The richest Armenian floristic regions in terms of alien species are Yerevan, Idjevan and Lori (Figs. 5, 6). The least invaded regions are Areguni and Upper Akhuryan, with seven and six species, respectively. On average, casual and naturalised alien species occupy two floristic regions, whereas invasive alien species occupy three. *Cirsium incanum*, *Conyza canadensis* and *Alliaria petiolata* are present in all Armenian floristic regions. The largest number of

Table 1 Life history traits of casual, naturalised and invasive alien plant species in Armenia. Values in parentheses represent percentages within each invasion status

Life history traits		Casual		Naturalized		Invasive	
Life form	Therophyte	6	(9.5)	10	(40.0)	11	(44.0)
	Geophyte	2	(3.2)	2	(8.0)	1	(4.0)
	Helophyte	0	(0)	1	(4.0)	0	(0)
	Hemicryptophyte	3	(4.8)	2	(8.0)	7	(28.0)
	Chamaephyte	9	(14.3)	2	(8.0)	0	(0)
	Phanerophyte	43	(68.2)	8	(32.0)	6	(24.0)
Growth form	Parasite	0	(0)	0	(0)	1	(3.9)
	Herb	14	(22.6)	16	(64.0)	18	(69.2)
	Vine	4	(6.4)	0	(0)	1	(3.9)
	Shrub	22	(35.5)	6	(24.0)	3	(11.5)
	Tree	22	(35.5)	3	(12.0)	3	(11.5)
Life cycle	Annual	6	(9.7)	10	(40.0)	11	(42.3)
	Biennial	0	(0)	0	(0)	4	(15.4)
	Perennial	56	(90.3)	15	(60.0)	11	(42.3)

Table 2 Introduction pathways of casual, naturalised and invasive alien plant species in Armenia. One species may have several introduction pathways. Values in parentheses represent percentages within each invasion status

Pathway	Casual		Naturalized		Invasive	
Ornamental	52	(71.6)	9	28.1)	8	(25.1)
Natural dispersal	5	(7.2)	8	(25.0)	7	(21.9)
Forestry	8	(11.5)	6	(18.8)	5	(15.6)
Seed contaminant	4	(5.3)	3	(9.4)	1	(3.1)
Vehicles	2	(2.9)	2	(6.25)	4	(12.5)
Transportation of soil	1	(1.5)	1	(3.10)	2	(6.25)
Food contaminant	0	(0)	0	(0)	2	(6.25)
Horticulture	0	(0)	2	(6.25)	0	(0)
Agriculture	0	(0)	0	(0)	1	(3.1)
Parasites on plants	0	(0)	0	(0)	1	(3.1)
People and their luggage	0	(0)	0	(0)	1	(3.1)
Release for nature for use	0	(0)	1	(3.1)	0	(0)

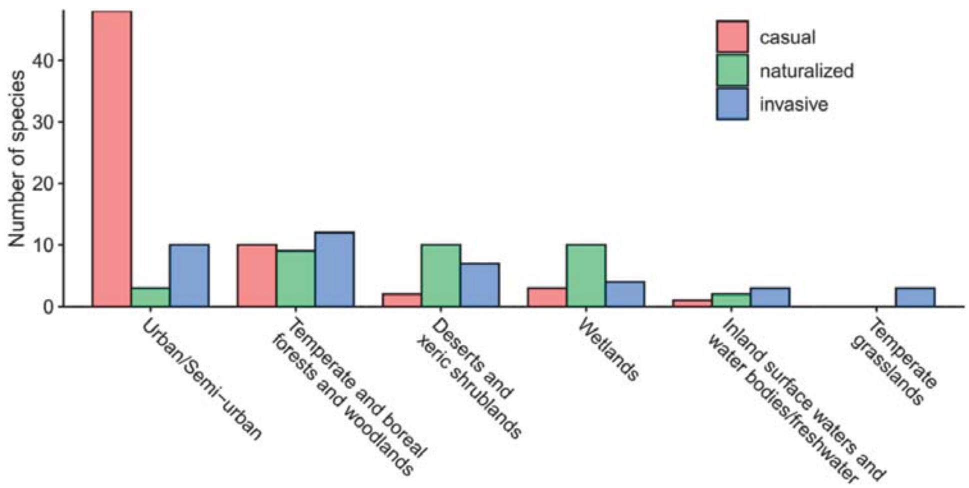

Fig. 4 Habitats where the species establish according to the IPBES units of analysis (Aidin and Obura 2019)

alien species is found in Yerevan, followed by Tavush and Lori provinces (Table 3); notably, these provinces also contain the highest frequencies of invasive and casual taxa.

The number of species has increased exponentially in the last century (Fig. 7). In particular, the number of casual alien species has increased six-fold since the beginning of the twentieth century.

The five species with the highest WRA scores were *Sigesbeckia orientalis*, *Solidago canadensis*, *Ailanthus altissima* (Fig. 8), *Ambrosia artemisiifolia* and *Silybum marianum* (Table 4). *Ailanthus altissima* is a tree from the *Simaroubaceae* family, whereas the others are primarily herbs of the families *Asteraceae* or *Poaceae*. The current classification of alien species as invasive, naturalised or casual was a good predictor of the WRA scores ($F_{(2,109)} = 39.55$, $p < 0.001$; Fig. 7), with notable differences. The WRA rejects all species currently classified as invasive in Armenia and 23 out of the 25 species classified as naturalised in the country. In contrast, 13 casual alien species would be accepted (i.e. are not predicted to have invasive potential), 22 species would require further evaluation, and 28 would be rejected. Twenty-four out of the 58 woody species assessed (six of them are invasive) and almost all herbaceous plants received more than 6 points and posed a significant threat (Appendix 1, Supplementary material).

Discussion

This study provides the first comprehensive assessment of the alien flora of Armenia. Similar work has also been carried out in Iran and, partially, in

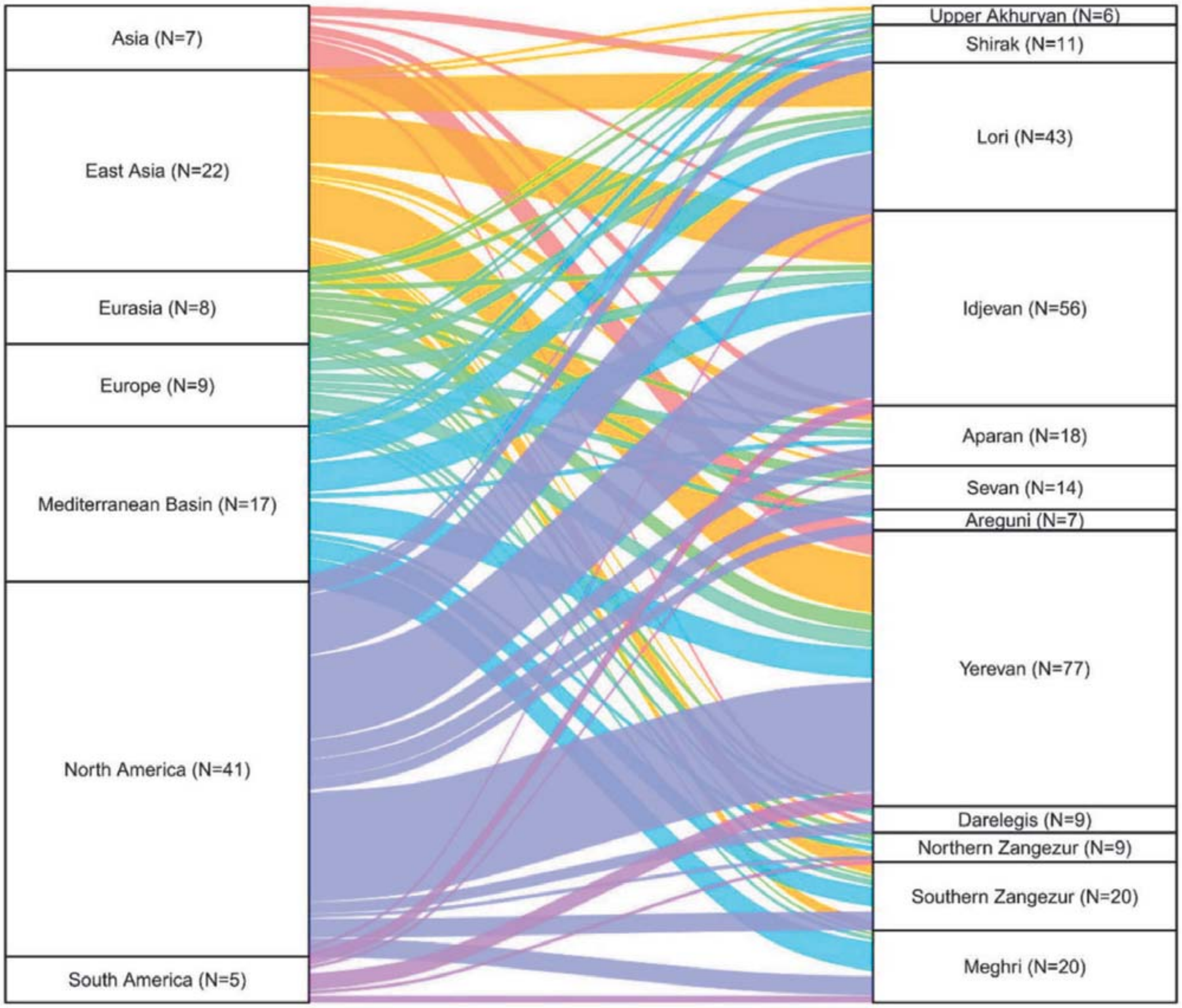

Fig. 5 Alluvial diagram relating the areas of origin of the alien flora in Armenia and the recipient floristic regions

Georgia and Azerbaijan (Abdiyeva 2019; Mikeladze et al. 2019; Sohrabi et al. 2023). We report the taxonomy, life form, introduction pathway, regions of origin and time of introduction of the 113 alien plant species (26 invasive, 25 naturalised and 62 casual) found in the wild in Armenia. We assessed the risk of invasion for each species. Our results confirmed that species classified as invasive have the highest scores and revealed that almost all naturalised species and 45% of casual species have the potential to become invasive (Pysek et al. 2009; Galan et al. 2023). Below, we describe these findings in detail.

Characteristics of the alien flora in Armenia

The most common families among the alien flora of Armenia are *Asteraceae*, *Rosaceae*, *Fabaceae* and *Poaceae*. All are known to be highly diverse families worldwide (especially in the Northern Hemisphere) and contain a large number of species considered invasive in Europe (Lambdon et al. 2008; Pyšek et al. 2017). Many invasive *Asteraceae* are therophytes and hemicryptophytes and were likely introduced accidentally, such as *Ambrosia artemisiifolia, Silybum marianum* and *Conyza canadensis* (Fayvush et al. 2020b, 2022, 2023). *Rosaceae*, the second most important family, encompasses casual phanerophytes

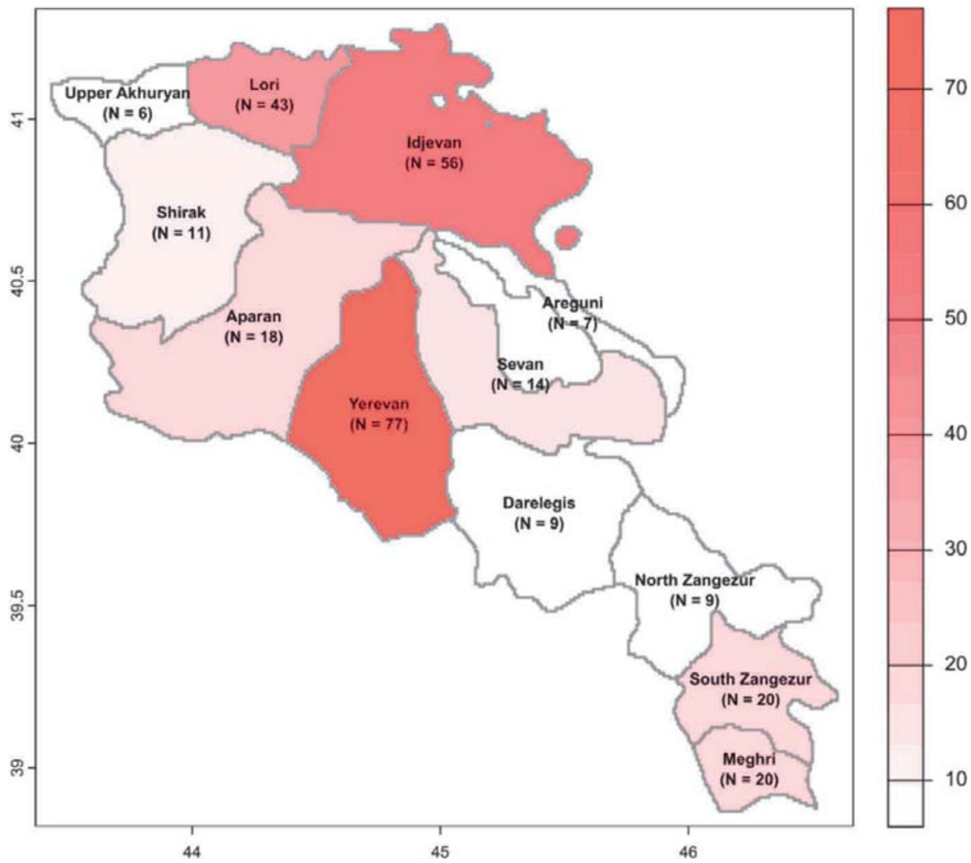

Fig. 6 Distribution of the alien flora by floristic regions in Armenia

Table 3 Occurence of alien plant species in administrative regions of Armenia

Administrative region	Alien species	Casual	Naturalized	Invasive
Aragatsotn	17	2	5	10
Ararat	23	2	9	12
Armavir	18	5	7	6
Gegharkunik	20	3	9	8
Kotajk	18	1	8	9
Lori	49	25	9	15
Shirak	14	1	4	9
Syunik	30	9	11	10
Tavush	53	28	10	15
Vayots Dzor	12	1	4	7
Yerevan	68	42	10	16

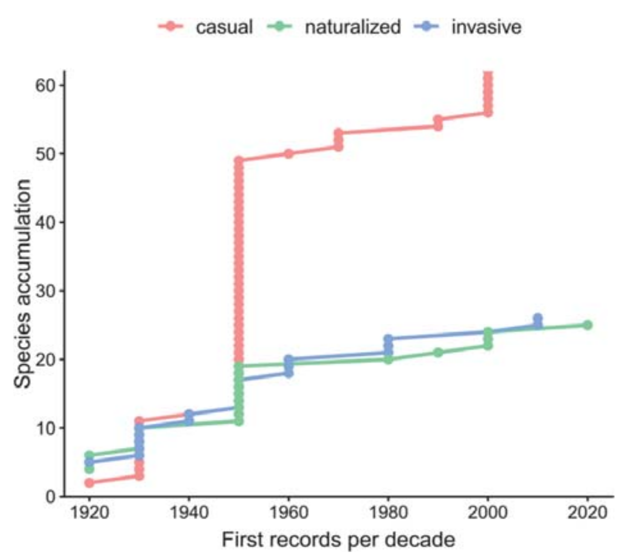

Fig. 7 Cumulative number of casual, naturalised and invasive species in Armenia per decade since 1900

introduced as ornamentals (e.g., *Cotoneaster horizontalis*, *Pyracantha angustifolia*, *Spiraea* spp.). *Fabaceae* are mostly naturalised phanerophytes (e.g., *Robinia pseudoacia, Cercis siliquastrum, Gleditsia triacanthos*) introduced also as ornamentals or in forestry. Finally, *Poaceae* comprise both therophytes and hemicryptophytes, many of which are invasive in neighbouring countries such as Iran, where they

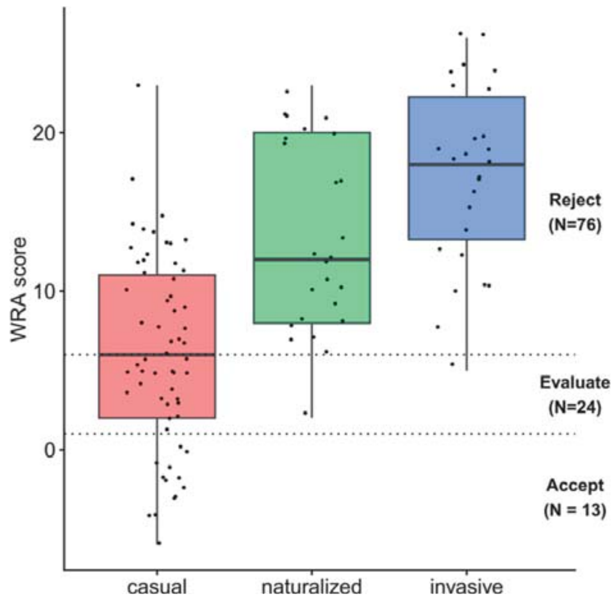

Fig. 8 Weed Risk Assessment scores of casual, naturalised and invasive alien plant species in Armenia. Dotted lines represent the thresholds for rejection, acceptance or requiring further evaluation according to WRA criteria. A high score (> 6) identifies a species likely to be of high risk (i.e. reject), a low score (< 1) identifies the species of low risk (i.e. accept) and intermediate scores (1–6) indicate that the species requires further evaluation. Values in parenthesis indicate the number of species in each group

are causing significant ecological and agricultural impacts (Sohrabi et al. 2025).

Introductions of ornamental plants are a major pathway of naturalized species globally (van Kleunen et al. 2018). Currently, more than 75% of the global naturalised alien flora are grown in gardens. In Armenia, 36% of naturalized and 31% of invasive species have been introduced as ornamentals. Some species introduced to Armenia in the 1930s and 1940s, such as *Ailanthus altissima, Acer negundo* and *Robinia pseudoacacia* have been introduced as ornamental plants and widely used in landscaping in Yerevan and other populated areas of the country. They have spread extensively and pose a serious threat to many ecosystems (Fayvush and Tamanyan 2014; Fayvush et al. 2018, 2022, 2023). Some of these phanerophytes are invasive and even form entirely new plant communities. In northern Armenia, we identified communities dominated by *Amorpha fruticosa* and *Ailanthus altissima* on mountain gorge slopes, where they are replacing the dominant species of shiblyak (*Paliurus spina-christi* thorn scrub: EUNIS 2022),

Yerevan, Idjevan and Lori are the most invaded floristic regions of Armenia. Our results support macroecological analysis conducted in other areas (e.g. Chytry et al. 2008), which found that regions with more alien species have high population density, dense communication networks and anthropic land-uses, which might increase the propagule pressure of alien plants. This primarily applies to the Yerevan floristic region, as it is home to approximately half of Armenia's population, boasts the most developed infrastructure (roads and railways) and has agricultural lands that cover almost the entire Ararat Plain. Furthermore, Yerevan itself is the base for major urban landscaping projects. The main transport routes connecting Armenia with Georgia and Azerbaijan and further on with other countries of the former Soviet Union, pass through the Lori and Idjevan floristic regions. Additionally, the significantly milder climate in these regions has facilitated the introduction of a significant number of alien species to the Vanadzor Botanical Garden and Idjevan Dendropark. These alien species were used in landscaping settlements in this part of Armenia. Currently, due to the intensification of road traffic between Armenia and Iran, special attention should be paid to the floristic regions along the highway connecting these countries (Meghri, North and South Zangezur and Darelegis). In the remaining floristic regions, a substantially smaller number of alien species have been recorded, most likely due to harsher climatic conditions and less intensive transport communications.

The analysis of the accumulation of alien plant species revealed an abrupt increase in the introduction rate around the 1950s. There might be two non-exclusive reasons for this peak. On one hand, in that decade, there were intensified greening efforts in Armenian populated areas, the creation of forest shelterbelts along highways, and, most importantly, the establishment of a 'green belt' around Yerevan to prevent strong, dusty winds during summer. All this required both the creation and development of a network of specialised nurseries for growing planting material and its importation from other regions of the former Soviet Union. On the other hand, it coincides with the publication of the first edition of the Flora of Armenia by Takhtajan. The preparation of this book supposed an increased effort in the survey, mapping and compilation of new plant records. This abrupt increase is mainly due to the presence

Table 4 Species of the alien flora of Armenia with the highest Weed Risk Assessment (WRA) scores (≥ 20), including information on region of origin, life history traits, invasion status, habitat and pathway of introduction. See Appendix I (Supplementary materials) for more information on all species

Species	Family	Origin	Life form	Life cycle	Growth form	Status	Habitat	Pathway	WRA score
Sigesbeckia orientalis	Asteraceae	Tropics	Therophyte	Annual	Herb	Invasive	Temperate and boreal forests and woodlands	6 - Natural dispersal	26
Solidago canadensis	Asteraceae	N America	Hemicryptophyte	Perennial	Herb	Invasive	Urban/Semi-urban	2 - Ornamental purpose	26
Ailanthus altissima	Simaroubaceae	China	Phanerophyte	Perennial	Tree	Invasive	Wetlands, Deserts and xeric shrublands, Temperate and boreal forest and woodlands	2 - Forestry; ornamental purpose	24
Ambrosia artemisiifolia	Asteraceae	N America	Therophyte	Annual	Herb	Invasive	Urban/Semi-urban	6 - Natural dispersal; 4 - vehicles	24
Silybum marianum	Asteraceae	Mediterranea	Hemicryptophyte	Biennial	Herb	Invasive	Deserts and xeric shrublands, Temperate and boreal forest and woodlands	4 - Vehicles	24
Acer negundo	Sapindaceae	N America	Phanerophyte	Perennial	Tree	Invasive	Temperate and boreal forests and woodlands, Inland surface waters and water bodies/freshwater	2 - Forestry; ornamental purpose	23
Arundo donax	Poaceae	Mediterranea	Chamaephyte	Perennial	Herb	Casual	Wetlands	6 - Natural dispersal	23
Phytolacca americana	Phytolaccaceae	N America	Chamaephyte	Perennial	Herb	Naturalized	Urban/Semi-urban	2 - Ornamental purpose	23
Robinia pseudoacacia	Fabaceae	N America	Phanerophyte	Perennial	Tree	Invasive	Temperate and boreal forests and woodlands	2 - Forestry; ornamental purpose	23
Polygonum orientale	Polygonaceae	Eurasia	Therophyte	Annual	Herb	Naturalized	Wetlands	2 - Horticulture	21
Setaria viridis	Poaceae	Eurasia	Therophyte	Annual	Herb	Naturalized	Deserts and xeric shrublands	6 - Natural dispersal	21
Solanum rostratum	Solanaceae	N America	Therophyte	Annual	Herb	Naturalized	Deserts and xeric shrublands, Urban/Semi-urban	4 - Vehicles	21

Table 4 (continued)

Species	Family	Origin	Life form	Life cycle	Growth form	Status	Habitat	Pathway	WRA score
Acorus calamus	Acoraceae	Asia	Helophyte	Perennial	Herb	Naturalized	Inland surface waters and water bodies/freshwater	1 - Release for nature for use	20
Conyza canadensis	Asteraceae	N America	Therophyte	Annual	Herb	Invasive	Deserts and xeric shrublands, Temperate and boreal forest and woodlands	6 - Natural dispersal	20
Leucanthemum vulgare	Asteraceae	Eurasia	Hemicryptophyte	Perennial	Herb	Invasive	Temperate grasslands, Wetlands	3 - Food contaminant	20
Psilurus incurvus	Poaceae	Mediterranea	Therophyte	Annual	Herb	Naturalized	Deserts and xeric shrublands	6 - Natural dispersal	20
Setaria verticillata	Poaceae	Europe	Therophyte	Annual	Herb	Naturalized	Deserts and xeric shrublands	6 - Natural dispersal	20

of casual species, which have accumulated six times faster than naturalized and invasive species. Because the control of alien plants is most successful at early stages of invasion (e.g. Sankaran et al. 2023), we suggest monitoring and controlling casual species to prevent their naturalization especially if they have high invasion potential.

Weed risk assessment of the alien flora in Armenia

Twenty-four out of 58 assessed woody species received more than 6 points in the WRA, indicating that they can pose a significant threat (Appendix 1, Supplementary material). Besides the aforementioned *Ailanthus altissima, Acer negundo* and *Robinia pseudoacacia, Clematis vitalba* is a high-scoring woody vine. *Clematis vitalba* was first discovered in Armenia in 1940 in the north of the country, but its growth in natural ecosystems was not confirmed for many years. Initially considered very rare, it was even included in the Red Book of Plants of Armenia (Tamanyan et al. 2010). Recent studies have shown that this species is reproducing and spreading, mainly along forest edges, likely transported by vehicles over distances of about 100 km from its initial location of discovery. Similarly, *Sambucus nigra* also has a high score, and it is widespread and expanding, particularly in Northern Armenia since the latter half of the twentieth century.

The vast majority of the assessed herbaceous plants (54 out of 56) also received a score greater than 6. *Siegesbeckia orientalis* and *Solidago canadensis* received the highest scores, although the former is quite rare and found mainly in disturbed habitats in the lowlands of northern and southern Armenia. In contrast, *Solidago canadensis* is widely used as an ornamental plant in gardens and parks and often escapes from cultivation. *Grindelia squarrosa* (WRA score = 19) was found in Armenia in 2015, and collectors consider that its appearance in Armenia is connected with the catastrophic earthquake of 1988 and subsequent restoration and construction work (Gabrielyan et al. 2016). In our opinion, the appearance of some high scoring herbaceous species in the country is associated with the development of tourism in recent decades and the intensification of car traffic (Fayvush et al. 2022).

Some herbaceous species with high scores are still rare in the country. In recent years, we have discovered a small population of *Phytolacca americana* along the roadside in northern Armenia. This species is classified as invasive across numerous European and Asian countries. It has been listed in the fourth batch of invasive alien species by the Ministry of Ecology and Environment in China (Xu et al. 2023); in Portugal it reached a WRA score of 29 (invasoras.pt/en/invasive-plant/phytolacca-americana; last updated 2021). *Polygonum orientale* was collected only once several years ago on the Ararat Plain, and updated data on its occurrence in the country are unavailable. These species are thermophilic and could establish if temperatures continue to rise. In Armenia average annual temperature has increased by 1.23 °C during the period of 1929–2016. According to the METRAS model and the RCP8.5 scenario (Melkonyan and Gevorgyan 2020), the average annual temperature in the lowlands of Armenia (800–1000 m above sea level) is expected to increase by nearly 5 °C by 2100, which will certainly influence the spread of many ‘potentially invasive’ plant species that require higher temperatures to thrive.

Conclusions

We provided the first checklist of the alien flora of Armenia, a landlocked country situated between Europe and West Asia. The number of alien species is low, but we believe it is not underestimated due to the country’s small size and its rich research tradition in botany and floristic expeditions. Starting with J. Tournefort and K. Koch in the eighteenth and nineteenth centuries (Tournefort 1717; Koch 1850), renowned Caucasian botanists such as A. Grossheim, A. Schelkovnikov, D. Sosnovsky and A. Takhtajyan continued exploring the region in the first half of the twentieth century (e.g. Lack 1978; Grossheim 1939–1967). A. Takhtajan’s school followed up in the second half of the twentieth century (Takhtajan 1954–2010).

The harsh climatic conditions and biogeographic isolation may explain the low number of invasive species found, especially in high-altitude areas. Many casual species occur in urban areas because they have been introduced as ornamentals and have not yet invaded natural and semi-natural habitats. However, they have the potential to become invasive and spread into more pristine areas, as many are thermophilic, and global warming may influence their distribution. A large number of alien species in Yerevan, Lori and Tavush administrative regions of Armenia is most likely due to the fact that these regions were and remain the main centers for the introduction and testing of species intended for landscaping in populated areas (the Yerevan and Vanadzor Botanical Gardens, the Ijevan Arboretum), from where these species “escaped”. Furthermore, the Lori and Tavush provinces were the main transit routes connecting Armenia with the countries of the former Soviet Union. The relatively large number of alien species in Syunik province is most likely explained by the province’s large area, as well as the current main transport route connecting Iran and Armenia, providing onward transit to Georgia.

Our species ranking should lay the foundations for policy and management of the alien flora, involving prevention, surveillance, monitoring, control and eradication.

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Declarations

Conflict of interest The authors have no conflict of interest to declare that are relevant to the content of this article.

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