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ALIEN FLORAS AND FAUNAS 20

Alien flora of Iran: species status, introduction dynamics, habitats and pathways

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Abstract This first inventory of casual, naturalized, and invasive alien plants in Iran provides a knowledge base for managing the threats associated with plant invasions in this country. Based on a wide range of data sources, including published work, reports, online databases, botanical records, and field observations, we identified 311 alien vascular plants, of which 131 are classified as casual, 167 naturalized, and 13 invasive. Therophytes are most represented among naturalized plants (50.9%), while phanerophytes (49.6%) are most represented among casuals. Poaceae, Fabaceae and Asteraceae are the families with the highest richness of alien species (35, 28, and 24, respectively). The largest fractions of naturalized taxa originated from South America and Central America (22.2% and 20.4% of all naturalized aliens, respectively). Horticulture and agriculture are the main pathways of new introductions of alien plants to Iran; this is reflected in naturalized species playing a major role in the weed flora of Iran, with about a half of them growing in agricultural habitats. Naturalized plants are also common in ruderal habitats, while

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casual plants commonly occur not only in these two types of human-disturbed habitats but also in open forest. We suggest that exploring the effect of bioclimatic conditions along with human population density in this large and diverse country could provide further information about alien species invasions; for that, future research should focus on mapping alien species spatial distribution in Iran and continue monitoring new arrivals in order to develop robust quarantine system at the national level.

Keywords Casual · Invasive · Inventory · Life form · Impact · Naturalized · Native range · Species richness

Introduction

Since 1970, the number of invasive alien species (IAS) per country has risen by about 70% across the 21 countries with detailed records available (Brondizio et al. 2019), and IAS from many taxonomic groups have serious impacts on native biodiversity, ecosystem functioning and human well-being (Pyšek et al. 2020). Plants are the most thoroughly studied group among alien organisms (Pyšek et al. 2008; van Kleunen et al. 2015); their establishment and spread can dramatically affect the native biodiversity by changing community composition and disrupting biotic interactions and other ecosystem processes (Hejda et al. 2009; Ehrenfeld 2010; Pyšek et al. 2012; Vilà and Hulme 2017). The negative impacts of alien plants are recognized by many studies, and invasions have been repeatedly listed among the causes of native species' habitat decline (Pratt et al. 2017; Bartz and Kowarik 2019; Langmaier and Lapin 2020; Richardson et al. 2022).

The knowledge of regional alien floras has increased considerably during the last decades (e.g., Inderjit et al. 2018; Vinogradova et al. 2018; Ansong et al. 2019; Leostrin and Pergl 2021; Omer et al. 2021; see Pyšek et al. 2017 for a global overview); such studies provide a solid basis for assessing the alien species' impacts on biodiversity, nature and human livelihood. For Iran, however, studies about alien plants are scarce and not comprehensive (Ghahremaninejad et al. 2011; Sohrabi et al. 2021). The last data available report 32 alien fish (Esmaeili et al. 2014), 79 alien plants (Pyšek et al. 2017), and four alien mammals (Dabiri et al. 2016). Yet, to improve knowledge in poorly studied regions of the alien species richness, their distribution, and how many species there are in different phases of invasion is important for many reasons, including a better understanding of factors determining local invasions (Pyšek et al. 2008, 2017; van Kleunen et al. 2015). This is particularly true for Iran, where the native biodiversity is threatened by invasions of new species along with water scarcity, land degradation, and pollution (Jowkar et al. 2016). Improving the knowledge of plant invasions in various habitats harbouring local plant communities is thus crucial to protect the high biodiversity of Iran. In addition, such regional data can be used to feed into global databases (van Kleunen et al. 2019) for analyses of the large-scale patterns of alien species richness that can serve as a basis for policymakers and their strategic decisions (Latombe et al. 2017).

In this study, we aimed to provide the first comprehensive assessment of the status of plant invasions in Iran, specifically to (i) identify the stage that alien plant species reached in the invasion process (i.e., casual, naturalized, and invasive, following the definitions proposed by Richardson et al. 2000), (ii) explore the taxonomic, biogeographical and ecological characteristics of this country's alien flora, and (iii) analyse whether the casual and naturalized alien species differ in their characteristics in Iran. We also elucidate (iv) the structure of habitats occupied by alien plants in Iran and (v) their introduction pathways.

Methods

Study area

Iran covers an area of 1,648,195 km^2 and is located in western Asia bordering the Caucasus Mountains and the Caspian Sea in the north and the Persian Gulf and Oman Sea in the south. This country is dominated by the Elburz Mountains in the north and the Zagros Mountains along its western boundaries. The central and eastern parts of the country are mostly covered by the Plateau of Iran, including several desert plains such as the Dasht-e Kavir in the center, Dasht-e Lut desert in the southeast (Zehzad et al. 2002; Noroozi et al. 2008) (Fig. 1).

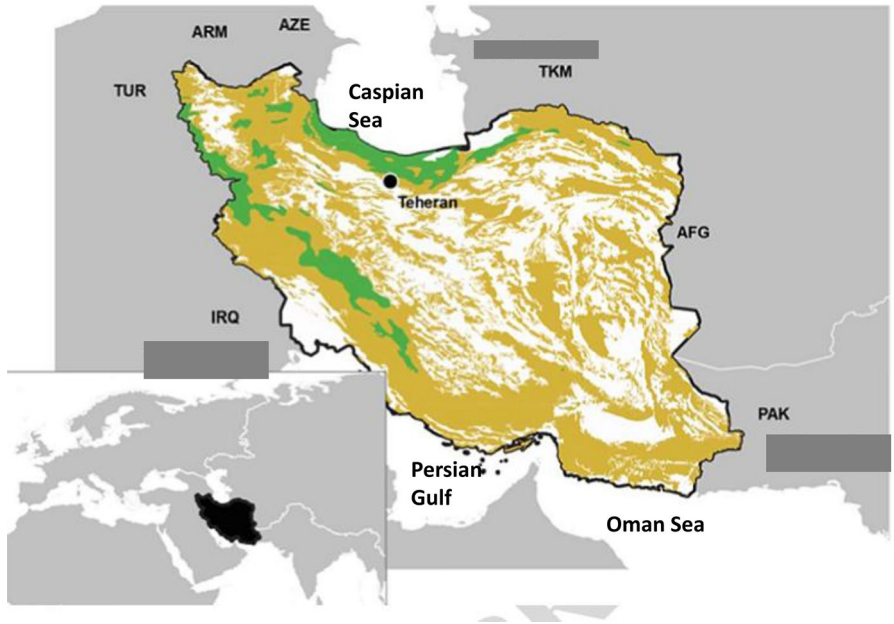

Fig. 1 The location of Iran in the west of Asia and its geographical features (green areas indicate the distribution of forests, light brown indicate mountain areas, and white indicates plains and deserts)

Iran is home to outstanding biodiversity that is due to its diverse geological formations, climates, and soils (Jowkar et al. 2016). The great difference between the two latitudes of the north and south of the country and the existence of different plains, altitudes, and climates in a vast land have contributed to the considerable plant diversity and number of vegetation types found in this large country. The biodiversity hotspots of Iran are mostly located in northern Iran along the Alborz and Zagros mountain ranges; the latter stretches from northwestern Iran and spans the whole length of western and southwestern Iran (Farashi and Shariati 2017). Approximately 8000 species of plants are native to Iran, of which 2100 are endemic (Noroozi et al. 2016). Almost 11% of the country (178,000 km^2) are protected areas (Zand et al. 2021). Iran has committed to the objectives of Convention on Biological Diversity, and has developed a national strategic plan for biodiversity conservation (Zand et al. 2021).

Sources of information

The presented inventory of vascular alien plant species is based on an extensive review of literature, personal observations, and consultations with local experts. Data was obtained from journal articles, scientific reports, and books (especially Iranian Flora) and complemented with distribution reports in major online compendia and databases such as CABI, GRIN, and GBIF along with direct field observations (see Supplementary Material 1 for references). Each taxon name and authority was checked according to the Plants of the World Online (POWO 2022). We only considered the species that are reported as growing in the wild. Alien plants are classified according to the stage they reached in the naturalization/invasion process (Richardson et al. 2000). Based on this concept, we use the following terms to describe the invasion status: (i) casual aliens, i.e., alien plants that may flourish and even reproduce occasionally in an area but do not form self-replacing populations and rely on repeated introductions for their persistence. (ii) Naturalized species (synonym: established species) form self-sustaining populations for several life cycles without direct intervention by people, or despite human intervention; they often recruit offspring freely, usually close to adult plants, and their persistence does not depend on ongoing input of propagules. (iii) Invasive species are a subset of naturalized species that produce reproductive offspring, often in very large numbers at considerable distances from the parents and/or site of introduction, and have the potential to spread over long distances (Richardson et al. 2000; Blackburn et al. 2011).

For each species, we collected information on its taxonomic affiliation; life form category developed by Raunkiaer (1934) and modified by Govaerts et al. (2000): therophytes, hydrophytes, helophytes, geophytes, hemicryptophytes, chamaephytes, nanophanerophytes and phanerophytes;; native range at the continent level; year of the first record in Iran (if available); and assumed pathway of introduction to the country (using the sources listed in Supplementary Material 1).

The classification of pathways followed the scheme of Hulme et al. (2008), classified into six categories: release (intentional introduction as a commodity for release); escape (intentional introduction as a commodity followed by an escape from cultivation); contaminant (unintentional introduction with a commodity); stowaway (unintentional introduction attached to or within a transport vector).

We also assigned each species to the most commonly invaded habitat types in Iran. Habitat categorization follows Hejda et al. (2015) to allow for comparison with other similar studies on alien species worldwide. The following habitat types were distinguished and used to classify species' habitat affinities: 1. Forests, 2. Open forests, 3. Scrub, 4. Grasslands (divided into 4a. Natural grasslands, 4b. Human-maintained grasslands), 5. Sandy, 6. Rocky, 7. Dryland, 8. Saline, 9. Riparian, 10. Wetland, 11. Aquatic, 12. Man-made (divided into 12a. Ruderal/urban habitats, 12b. Agricultural habitats). Each species could be affiliated to more than one habitat, pathway category, and area of origin; therefore, the sums of the numbers of habitat and pathway affiliations exceed the total numbers of species recorded.

Statistical analysis

To evaluate the relationship between the number of species recorded and the year of the first record, performed for all species and categories of species status separately, we used the Spearman's correlation test as implemented in ggscatter function in R (Kassambara 2020). To identify significant associations of species status (casual, naturalized, and invasive) with life form, habitat type, the continent of native range, and pathways of introduction, we used Pearson's chi-squared test of independence to test the relationship of the first matrix. In general, the recommended criteria to perform the Pearson's chi-square statistic are the total sample size of 10 times the number of cells in the contingency table (Legendre and Legendre 1998) or that all expected values are greater than 1 (as recommended by Fienberg 1980). Because small expected values can decrease or increase the chi-square statistic, we removed some factor levels that had 0–2 records per cell. To evaluate the association between life form and species status, we removed chamaephytes and helophytes because records for some status categories were missing. Similarly, to account for the association between habitat types and species status, we removed grassland, rocky, saline and scrub habitats (see Table 2). Because there were many regions of origin from which there are no invasive species in Iran (Australasia, Europe, Pacific Islands and Temperate Asia), we did not formally test the association between species origin and invasion status. Finally, to evaluate the association between the pathway of introduction and invasion status, we removed the stowaway category; note that one species can have more than one pathway of introduction. The calculations were made in R version 2022.02.0 (R Core Team 2022).

Results

In total, we recorded 311 alien taxa belonging to 69 families, of which 131 are classified as casuals, 167 as naturalized, and 13 as invasive in Iran. Among the 13 invasive plants, six and three reach the highest impact, > 4 and MR (major), in two commonly used classification schemes, GISS and EICAT, respectively (Table 1) (Sohrabi et al. 2021, 2022a).

We obtained data on the first record in Iran for 252 species, ranging from 1820 to 2021. There was a significant increase in the number of recorded species with time since introduction for all alien species taken together (Fig. 2d) and for naturalized species separately (Fig. 2b), but not for casual (Fig. 2a) and invasive species (Fig. 2c).

The majority of alien species in Iran are therophytes and phanerophytes, represented by 106 and 91 taxa, respectively; the number of naturalized taxa with other life forms does not exceed 40 (Fig. 3). Therophytes were markedly over-represented among

Table 1 Invasive alien plants in Iran and their main characteristics

Invasive species	Family	Life form	Year of the 1st record	Native range	Pathway	EICAT	GISS score
Ailanthus altissima	Simaroubaceae	Phanerophyte	1950	East Asia	Escape	MR	4.54
Ambrosia psilostachya	Asteraceae	Therophyte	2010	North America	Contaminant	MR	3.8
Anredera cordifolia	Basellaceae	Geophyte	2015	South America	Escape	MO	3.63
Araujia sericifera	Apocynaceae	Nanophanerophyte	2000	South America	Release	MO	3.8
Azolla filiculoides	Azollaceae	Hydrophyte	1965	East Asia	Release	MO	3.84
Euphorbia maculata	Euphorbiaceae	Therophyte	2008	Eastern United States	Contaminant	MN	4.23
Ipomoea indica	Convolvulaceae	Hemicryptophyte	2019	North America	Escape	MO	3.62
Ipomoea purpurea	Convolvulaceae	Therophyte	2012	Mexico and Central America	Escape	MO	4.14
Ipomoea nil	Convolvulaceae	Therophyte	2010	The tropical Americas	Contaminant	MO	3.49
Pontederia crassipes	Pontederiaceae	Hydrophyte	2000	South America	Release	MR	4.55
Prosopis juliflora	Fabaceae	Phanerophyte	2000	South America	Release	MO	4.23
Rottboellia cochinochinensis	Poaceae	Therophyte	2013	Africa, Central America and Tropical Asia	Contaminant	MO	4.15
Sida rhombifolia	Malvaceae	Hemicryptophyte	2003	North America	Contaminant	MO	3.48

The EICAT and GISS scores are taken from Sohrabi et al. (2021, 2022a). EICAT: *MR* major; *MO* moderate. GISS scores (shown the total) range from 0 (no impact) to 5 (major impact)

naturalized species (50.9%), followed by phanerophytes (14.4%), geophytes (11.4%), hemicryptophytes (8.4%), nanophanerophytes (7.2%), and hydrophytes (1.8%). In contrast, the proportion of phanerophytes was higher among casual species (49.6%), followed by nanophanerophytes (19.8%), therophytes (12.2%), and other life forms less represented (Fig. 3). The association between life form and species status was significant ($\chi^2 = 86.5$ d.f. = 10, $P < 0.001$).

The top three families with the largest numbers of plant species are the same for native and alien species: Asteraceae, Fabaceae, and Poaceae (Fig. 4). In total, the flora of Iran has approximately 8000 native species, and here we report 311 alien species in the country. In relation to the botanical families separated by status, most naturalized species belong to the Poaceae (n = 22), Asteraceae (n = 18) and Amaranthaceae (n = 13). Fabaceae includes the greatest number of casual species (n = 17) (Fig. 4b), followed by Poaceae (n = 12) and Myrtaceae (n = 10), while Convolvulaceae is the richest in invasive plants (n = 3).

Alien taxa are present in all 13 habitat types examined in the present study, being most abundant in ruderal (281 out of 311 species or 90.4%), agricultural (33.1%), open forest (19.6%), and dryland (9.6%) habitats (Table 2). While naturalized taxa are more evenly distributed among habitats, casuals are markedly concentrated in ruderal, open forest and agricultural habitats; these categories account for 84.3% of all casual alien species recorded in Iran (Table 2). There was a significant association between habitat type and species invasion status ($\chi^2 = 63$, d.f. = 16, $P < 0.001$). We found a higher proportion than expected of invasive (n = 6) and naturalized species (n = 82) in agricultural habitats, naturalized taxa in dryland (n = 20), sandy (n = 20), riparian (n = 11) and wetland (n = 21), invasive species in open forest (n = 6) and riparian habitats (n = 3), and casuals in ruderal habitats (n = 123).

Data on the native range were available for all 311 species. The majority of alien records are from South America (n = 94 records), Central America (87), North America (73) and Tropical Asia (65), followed by Africa (53), Temperate Asia (40), Europe (30), Australasia (23 records) and Pacific Islands (8) (Fig. 5). For naturalized taxa, the greatest proportions of species were introduced from South America (22.2%) and Central America (20.4% of all naturalized species records in Iran), North America (15.6%), and Tropical Asia (12.7%). Most

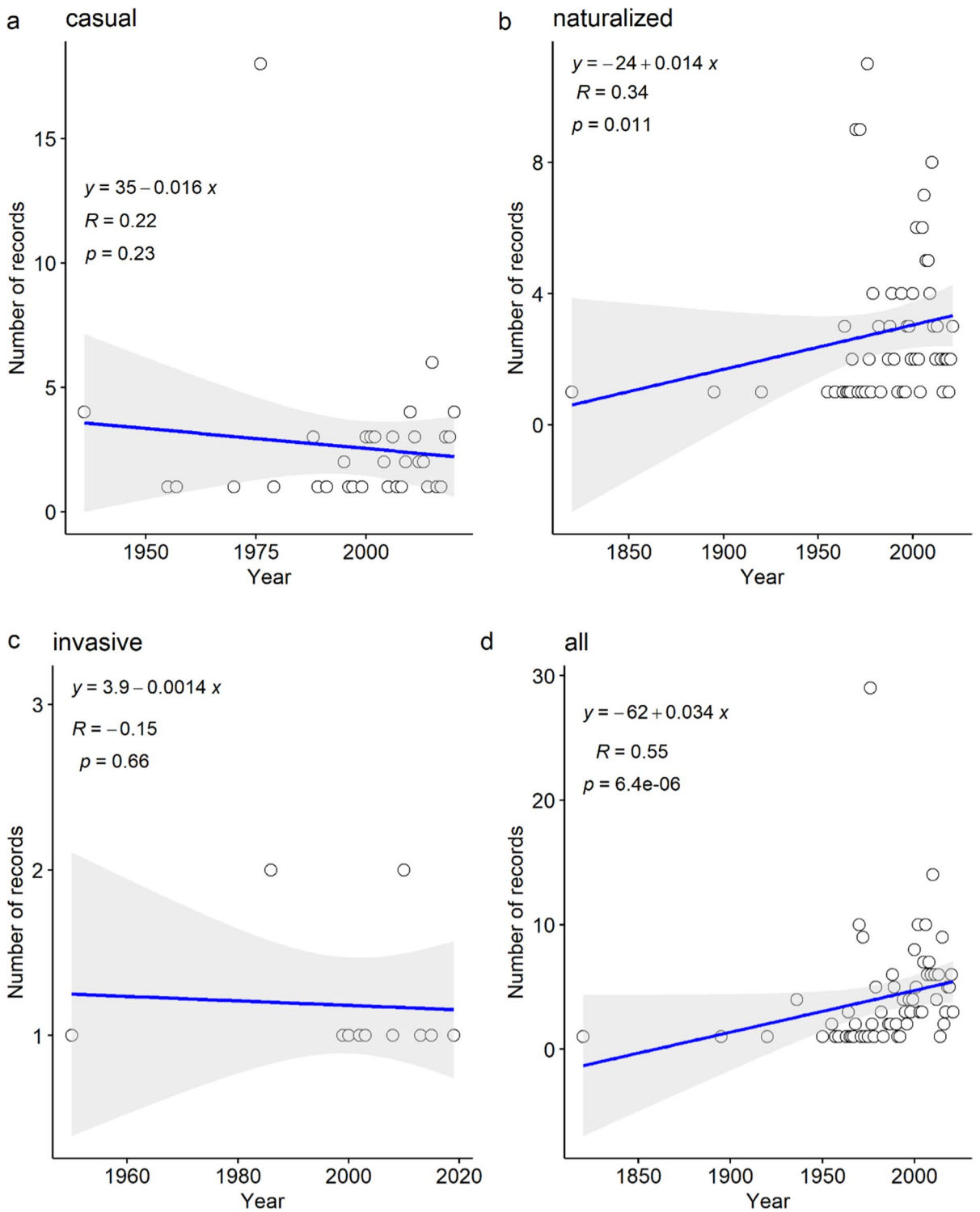

Fig. 2 Increase in number of the first records in Iran over time for **a)**casual (n = 85), **b** naturalized (n = 154), **c** invasive species (n = 13) and **d** all alien species (n = 252). A significant increase in the number of records over time was found for naturalized species and for all alien species taken together

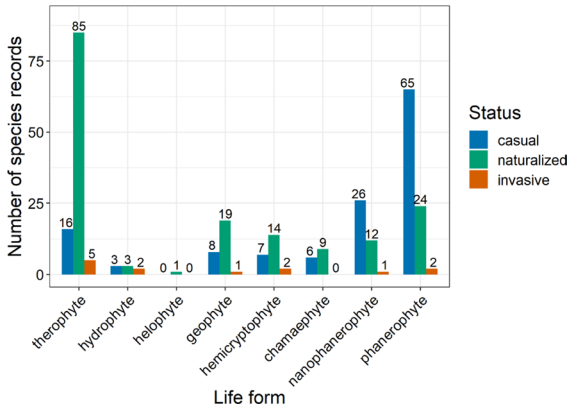

Fig. 3 The number of alien species in Iran with particular life forms according to their invasion status. A distinct proportion of life forms was found for the different status categories (see text for details)

invasive species originated in South America (38.1%), and Central America (23.8%), followed by North America and Tropical Asia (14.3% each) (Fig. 5).

Information on the pathway of introduction was obtained for 307 species; the four species without known pathway are classified as naturalized: *Calamagrostis decora*, *Paspalum dilatatum*, *Setaria parviflora,* and *Sisyrinchium rosulatum*. Of the total number of species records (reflecting that some species are classified in multiple categories), 171 (47.9%) escaped from cultivation, 100 (28%) were introduced as contaminants, 68 (19%) were released and 18 were introduced as stowaway (5%) (Fig. 6). For naturalized species (184 records), there is a prevalence of the contaminant pathway (48.9% of the total) followed by escape (30.4%). Most casual taxa (111 records) escaped from cultivation (69.8%), and for invasives (14 records) the main pathways of introduction are contaminant and release (corresponding to 35.7% each). We found a significant association between pathway of introduction and species invasion status ($\chi^2 = 99.28$, d.f. = 4, $P < 0.001$). There is a higher proportion than expected of invasive species (n = 5) and naturalized species (n = 90) that were introduced by the contaminant pathway, as well as a higher proportion of casuals via escape (n = 111) and of casuals (n = 38) and invasives via release (n = 5).

Discussion

This study, reporting 311 plant taxa alien to Iran, represents the first comprehensive overview of plant invasions in this country using a standardized classification of species invasion status (Richardson et al. 2000; Blackburn et al. 2011). Furthermore, the data collected contribute to long-lasting global efforts to assess the actual numbers of alien plants in regions of the world (Silva and Smith 2004; Crall et al. 2006; Richardson and Pyšek 2006; Pyšek et al. 2018; van Kleunen et al. 2019). Standardized, reliable, and actual data are a necessary prerequisite for understanding global naturalization patterns and their underlying processes and reporting biodiversity status in terms of essential biodiversity variables (van Kleunen et al. 2015).

A considerably lower number of alien plants was reported for Iran in previous publications (79 in Pyšek et al. 2017 from GloNAF database, based on CABI 2014), clearly reflecting low research and publication intensity or lack of focus on plant invasions, but to some extent also the dynamics of species introductions and subsequent naturalizations (29 species in our data set were introduced after 2014, i.e., the date CABI database was accessed for the GloNAF database). Our data revealed that 3.9% of the alien taxa in Iran are invasive; assuming that these species have impacts, it is a proportion that is within the range predicted by the tens rule of biological invasions (Williamson and Fitter 1996; Richardson and Pyšek 2006; Jeschke and Pyšek 2018). The impact of invasive plants in Iran has been assessed in a previous study and showed that among the 13 invasive species recorded, six and three reached the highest impact scores, > 4 and MR (major), in two commonly used classification schemes, GISS and EICAT, respectively (Table 1) (Sohrabi et al. 2021, 2022a).

The trend of moderately increasing alien species records during the past decades holds for the number of both casual and naturalized species plant taxa in Iran. The lack of information about the numbers of naturalized plants in Asia, compared to other continents, might be related to the lower rate of colonization by Europeans; large parts of Asia have only recently opened up to inward movements of people and plants. Consequently, some regions are still poorly surveyed, especially in the western parts of Asia (van Kleunen et al. 2015). For example, the

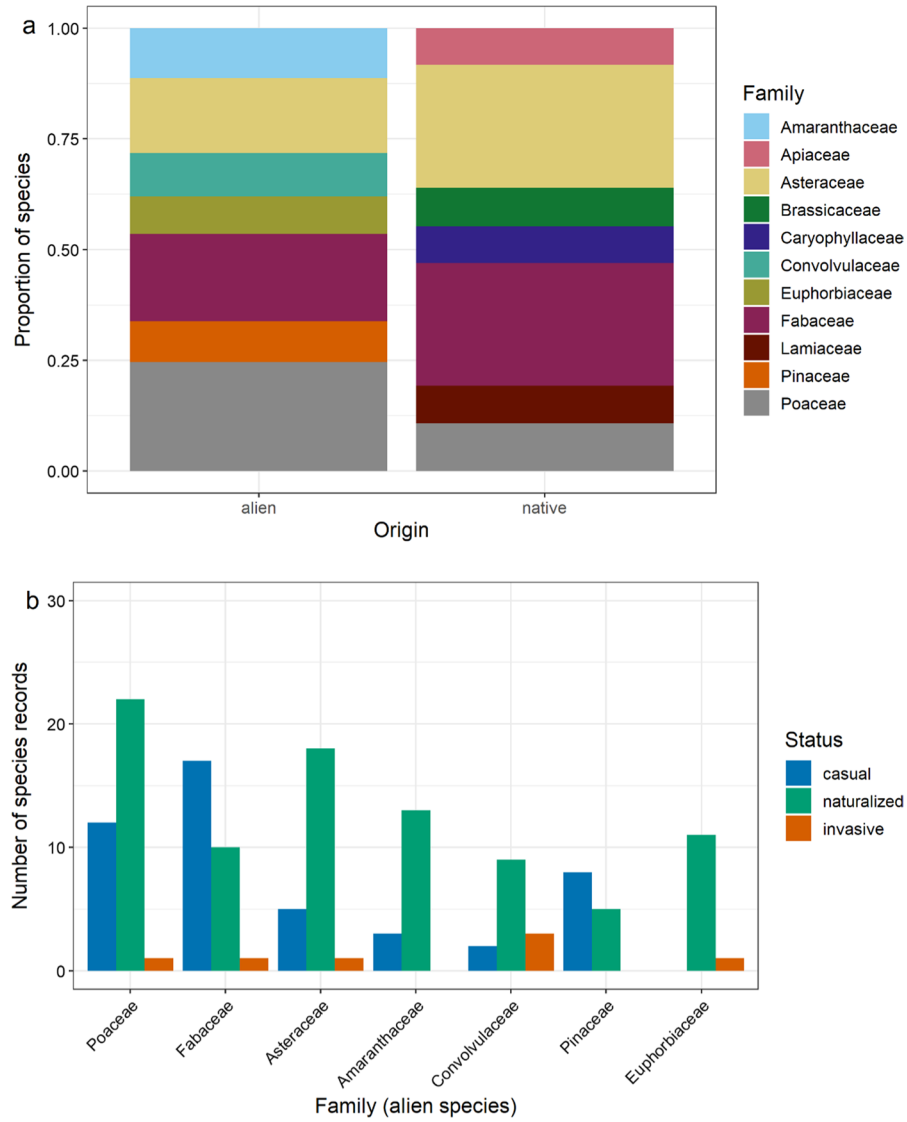

Fig. 4 Plant families with the largest number of species in Iran. **a** Proportion in the seven main families of alien (left) and native species (right). These seven main families contain 4630 native species (out of the total of 8000 native species in Iran, or 57.8%) and 142 alien species (out of 311 alien species reported here for the country, or 45.7%). **c** main families of alien species (as in **a**), separated by status

recorded numbers of alien species in most countries in the west of Asia are very low in comparison to the countries located in the eastern part of the continent with more intensive research in botany and biological invasions, such as Japan (> 1500 species), Taiwan (> 650 species), Philippines (> 700 species) and China (> 500 species) (Pyšek et al. 2017). This suggests that alien floras in the western-Asian countries are still underestimated. Furthermore, the low numbers of recorded alien plants are likely to be related to arid climates and consequently less successful establishment in some western countries in Asia. Pyšek et al. (2017) showed, using the rate of increase in naturalized plant species numbers with the area as a measure of the region's susceptibility to invasion, that invasions were rather fast in colder temperate and mediterranean regions and slow in arid zonobiomes. Other studies depicted the effect of harsh climate (drought, heat, and cold) as the possibly important limiting factor for the future naturalizations of alien plants (Lambdon et al. 2008; Häkkinen et al. 2022).

The majority of naturalized aliens in Iran are herbaceous, in particular annuals, represented by therophytes. The high fraction of herbs among aliens was reported by many other studies (Weber et al. 2008; Vinogradova et al. 2018; Ansong et al. 2019; Leostrin and Pergl 2021; Omer et al. 2021); their predominance among the naturalized plants can be explained

Table 2 Number of alien species in Iran in each habitat type, according to their invasive status (casual, naturalized, and invasive), as well as for all aliens

Habitat code	Habitat name	Casual	Invasive	Naturalized	All aliens
1	Forest	6	3	10	19
2	Open forest	19	6	36	61
3	Scrub	0	1	9	10
4	Grassland	2	0	17	19
5	Sandy	1	1	20	22
6	Rocky	0	0	1	1
7	Dryland	9	1	20	30
8	Saline	2	0	6	8
9	Riparian	2	3	11	16
10	Wetland	3	1	21	25
11	Aquatic	4	2	10	16
12a	Ruderal habitats	123	8	150	281
12b	Agricultural habitats	15	6	82	103

The habitat classification was modified from Hejda et al. (2015)

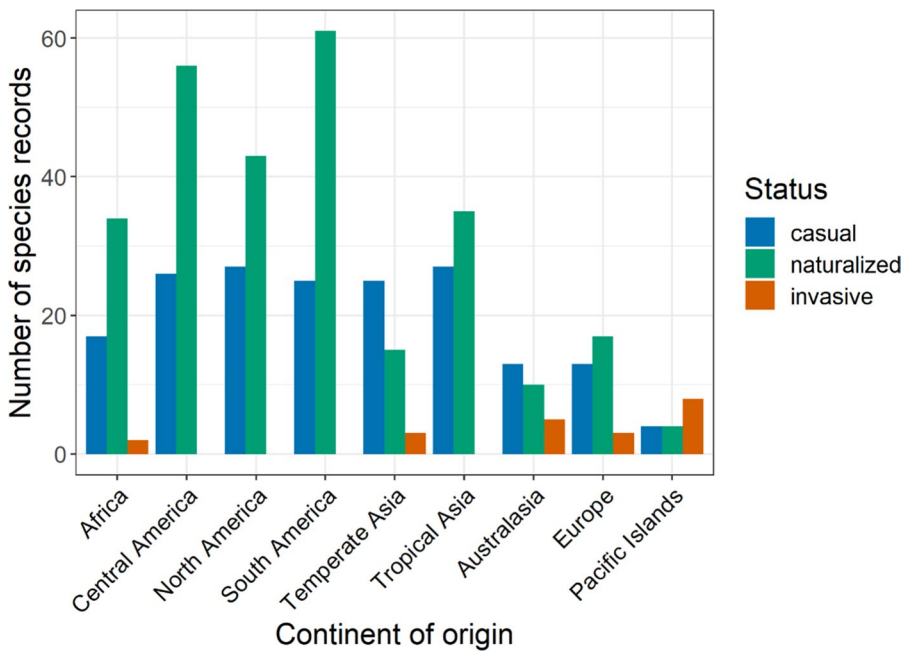

Fig. 5 The number of species by the region of origin shown for casual, invasive, and naturalized species. Note that a single species can have more than one continent of origin

by their higher establishment success compared to woody plants (Schippers et al. 2001). That most trees and shrubs among alien plants are casual is most likely related to horticultural use, timber production, and erosion control, i.e., the purposes of introducing them to Iran, and frequent subsequent escape from cultivation. The great proportion of annuals,, i.e. therophytes, among the alien flora of Iran corresponds to the pattern reported by a study on naturalized alien flora of the world (Pyšek et al. 2017), as well as by some regional studies (Inderjit et al. 2018; Guarino et al. 2021). The prevalence of annuals can be related to the combined effect of seasonal drought and disturbance due to multiple land-use patterns.

The families with the most alien species in the Iranian flora are Poaceae, Asteraceae, and Fabaceae, similar to other studies with a focus on alien floras, especially in the temperate zone (e.g., Lambdon et al. 2008; Pyšek et al. 2017; Vinogradova et al. 2018; Omer et al. 2021). Similarly, Asteraceae and Poaceae contain the highest numbers of naturalized and invasive species in alien floras of many other

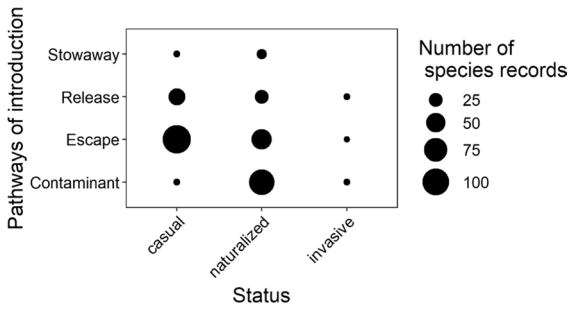

Fig. 6 Pathways of introduction of alien species (classified according to Hulme et al. 2008) in Iran by species status (note that the same species can have more than one pathway)

countries (Daehler 1998; Lambdon et al. 2008; Pyšek et al. 2017). They are the largest plant families; since they are being usually introduced in high numbers, it is more likely that they supply many naturalized and invasive species. Besides, the Fabaceae family has a large number of casual plants, with an arid climate likely contributing to this phenomenon (Wu et al. 2004; Zerbe et al. 2004). There is a close correspondence of taxonomic affiliations in the native and alien flora of Iran, with the three most commonly represented families being the richest in both species groups; similarly, a close relationship of alien and native species per family was reported for South Africa (Germishuizen et al. 2006). Comparing the information on functional traits (e.g., seed weight, plant height, dispersal mode, and flowering time) of native and alien flora can reflect the primary environmental and biotic filters; this knowledge can be useful for predicting future naturalizations.

Iran harbours diverse ecosystems ranging from humid and semihumid to warm and arid (Azizi Jalilian et al. 2020), and this contributes to the accommodation of species from regions with a variety of climates. One country neighboring Iran, for which information on naturalized flora is available, is Turkey; the structure of aliens with regard to their origin is similar to our study (Uludag et al. 2017). The main donors of alien plants to Iran are the botanically most species-rich continents (South America and tropical Asia), but the patterns are affected by historical human movements, such as the long history of trade within the Old World (Keller et al. 2011). The pattern we observed is in accordance with previous studies that explored the origin of alien floras (Inderjit et al. 2018; Leostrin and Pergl 2021).

Naturalized plants mostly occur in disturbed man-made sites such as ruderal and agricultural habitats. Casual plants that are predominantly woody are mostly present in ruderal and open-forest habitats. The dominance of casual, naturalized, and invasive plants in disturbed ruderal habitats and in agricultural areas is commonly reported in various regions (Weber et al. 2008; Uludag et al. 2017; Omer et al. 2021). The existing strong correlation between the numbers of invasive (sensu IUCN 2000) and all naturalized taxa (Richardson et al. 2000; Blackburn et al. 2011) is important for predicting future numbers of invasive plants (Pyšek et al. 2017). Based on our study, a relatively large proportion of naturalized species (≈ 30%) are classified as weeds in Iran (Sohrabi et al. 2011, 2022b; Zand et al. 2017), which indicates that naturalized species play an important role in the country's weed flora.

In Iran, the lack of awareness regarding invasive alien plants persists among land managers, potentially leading to the continued trade and use of alien plants. The invasive plants continue to be traded by horticulturalists (suppliers and consumers), as reported by Cronin et al. (2017). According to Padayachee et al. (2017), the majority of plants introduced for horticulture escape or are released. In our study, horticulture and agriculture are the main uses promoting the introduction of alien plants to Iran, and given the magnitude of the horticultural industry, it is likely that the risk of escape will continue to be important (Novoa et al. 2015; Faulkner et al. 2016; Visser et al. 2016; Cronin et al. 2017). International trade, limited awareness of the risk from contamination of agricultural commodities as well as the lack of a robust quarantine system in Iran are important drivers for new accidental introductions.

Two major landscapes in Iran, desert and mountain, with their typical climatic conditions, play a major role in shaping biodiversity patterns (Rahnemai 2014). Most protected areas and species-richest areas are restricted to mountain ranges and forests (Zehzad et al. 2002). With increasing pastoralism, urbanization, road construction, and ongoing climate change, the risk of biodiversity loss in the Iranian mountains is very high (Noroozi et al. 2019). The process of reducing biodiversity is accompanied by an increasing rate of alien species introductions, as we showed in our study. To protect the habitat and species

diversity of Iran, a knowledge-based national strategy on invasive alien species needs to be developed.

This study provided the first comprehensive inventory of casual, naturalized, and invasive alien plants in Iran, which was the main objective of our research. However, we expect it will promote further studies and raise awareness of threats associated with the ongoing plant invasions in the country (Sohrabi et al. 2021). Futhermore, the associated database (Supplementary Material 1) can support priority setting, risk analysis, monitoring, and tailored plans mitigating the negative impacts of invasive plants and for the conservation of native biodiversity and ecosystem services.

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Data availability Raw data are presented as supplemetary file.

Declarations

Conflict of interest The authors declare no conflict of interest.

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