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ORIGINAL PAPER

Quantifying the potential impact of alien plants of Iran using the Generic Impact Scoring System (GISS) and Environmental Impact Classification for Alien Taxa (EICAT)

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Abstract Assessing the impacts of alien plant species is scientifically important and critical for supporting invasion-related policies. Generic Impact Scoring System (GISS) and Environmental Impact Classification for Alien Taxa (EICAT) are standardized schemes to evaluate, compare, and eventually predict the magnitudes of the variety of impacts invasive species can have. Here, we apply these two systems to classify alien plants of Iran according to the magnitude of their environmental and socioeconomic impacts. A review of published literature and online resources was undertaken to collate information on the reported environmental and socioeconomics impacts of 27 alien plants in Iran. The resulting data ranked species by their total sum of impact scores and by their highest scores. According to total impact scores from GISS *Eichhornia crassipes*, *Ailanthus altissima*, *Imperata cylindrica*, *Amsinckia menziesii,* and *Paulownia* sp. had the highest impacts. About 60% of alien plants assessed had higher environmental impacts than socioeconomic impacts, 18% had higher scores for socioeconomic impacts, and 22% scored the same in both categories. According to EICAT, *Ulex europaeus*, *Ambrosia psilostachya*, *E. crassipes*, *A. altissima,* and *A. menziesii* were the five species with major impacts; other 16 species (59%) were classified as with moderate impacts, five with minor and two of minimal concern. Seven species had similar rankings

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by both GISS and EICAT. The deficit of scientific literature to quantify impacts on complex ecosystem services in Iran or emphasis on the reversibility of impacts in the EICAT protocol could explain differences in ranking of species by the two schemes. GISS and EICAT could be used to link impact magnitudes and type (environmental or socioeconomic) to biological traits to understand and forecast species with different types of impact.

Keywords Alien plants · Competition · Data deficient · Environmental impact · Socioeconomic impact

Introduction

The invasion by alien plants in novel habitats poses a serious concern for biodiversity and ecosystems globally (Pyšek et al. 2012a, b, Brondizio et al. 2019). Not all alien species have a significant negative impact (Vilà et al. 2010), and the effect can differ among regions and can change in time. Furthermore, the introduction of many alien species can be associated with both negative and beneficial consequences within various target groups (van Wilgen and Richardson 2014). The impacts of alien species, particularly their subset called invasive (Richardson et al. 2000, 2011), were listed as one of the threats to biodiversity, resulting in the competition for space or food, predation, habitat destruction or degradation, and the transmission of diseases and parasites (Foxcroft et al. 2013; Kumschick et al. 2015a, b). They also have significant socioeconomic and health impacts in their new habitats (Bacher et al. 2018; Schlaepfer 2018). The impact is usually defined as a measurable change in ecological or socioeconomic pattern or process brought about by a biological invasion (Pyšek et al. 2012a, b, Ricciardi et al. 2013, Hulme et al. 2013; see Jeschke et al. 2014 for a detailed discussion of measures used to define impact). The impact of biological invasions will continue to increase in the future by intentional and unintentional translocation of organisms across biogeographical boundaries (Essl et al. 2011; Genovesi et al. 2015). Considerable effort is now being devoted towards developing robust methods for forecasting and quantifying impacts and developing effective prevention and management interventions (Blackburn et al. 2014; Nentwig et al. 2016; Turbé et al. 2017; Bacher et al. 2018; Vilà et al. 2019). Systematic impact-assessment protocols that synthesize data on impact from primary scientific studies help to identify and prioritize the most harmful alien species and assess the relevance of extrapolations from local-scale studies to other areas of interest, such as management and decision making (Kumschick et al. 2015a, b; Vilà et al. 2019). Impact assessments provide a scientific basis for allowing or prohibiting the introduction, commercial use, and import of species that are traditionally classified into ''whitelists'' and ''blacklists'', respectively (Burgiel and Perrault 2011). Many impact assessments have been applied at a range of spatial scales (Baker et al. 2008; D'hondt et al. 2015; Rumlerová et al. 2016; Evans et al. 2016; Pergl et al. 2016; Nentwig et al. 2018) and their results are fundamental for conservationists, environmental managers, and policymakers to prioritize efforts for preventing, monitoring, controlling and eradicating alien species (Pergl et al. 2016).

According to a recent study, there are 26 impact assessment schemes currently available, some of them specific for countries, others regional or global; 16 are specifically designed for plants, two for aquatic organisms, and eight applicable to a wide range of taxa (Vilà et al. 2019). The Generic Impact Scoring System (GISS) and the Environmental Impact Classification for Alien Taxa (EICAT) are two of the best developed impact-assessment schemes that meet the demands for transparency, clarity, user-friendly application, broad scope, and reproducibility that are required for an efficient protocol. GISS is a standardized tool to quantify the impact of alien species (Nentwig et al. 2016), developed for alien mammals, and later applied to birds, fish, aquatic invertebrates, and plants in Europe (Nentwig et al. 2010; Kumschick and Nentwig 2010; van der Veer and Nentwig 2015; Laverty et al. 2015; Rumlerová et al. 2016; Novoa et al. 2016). GISS includes 12 impact categories encompassing six for environmental impact and six for socioeconomic impact (van der Veer and Nentwig 2015). EICAT is an impact assessment protocol developed by Blackburn et al. (2014), recently officially adopted by IUCN as a tool for classifying the environmental impacts of alien species (https://www.iucn.org/news/species/202009/iucn-standard-support-global-action-invasive-alien-species). Twelve mechanisms are scored by which alien taxa cause deleterious impacts in areas to which they were introduced. For each mechanism, there are several criteria against which taxa should be evaluated (Hawkins et al. 2015).

Iran is located in the arid belt of the eastern hemisphere in West Asia, bordering the Caspian Sea in the north and the Persian Gulf in the south. Six climatic zones are recognized in Iran based on rainfall and temperature (Alizadeh-Choobari and Najafi 2018), and the country's vegetation consists of a variety of vegetation types. Nearly 190 families of vascular plants are known to occur in Iran, with more than 8,000 vascular plant taxa, approximately 30% of which are endemic (Emami and Aghazari 2010; Norroozi et al. 2016). The broad range of climates and environmental conditions creates suitable conditions for the establishment of alien plants, some of them to become invasive alien species (IAS). The number of introduced and established alien plants in Iran is growing in response to human population growth, increasing transport capacity, economic globalization, and climate change (Sohrabi et al. 2017). Many plant species have been introduced to Iran for various purposes, such as agriculture, forestry, and horticulture, with some beneficial species, however, spreading beyond cultivation, threatening natural or agricultural ecosystems (Sohrabi et al. 2016, 2017). More than 35 IAS (fish, plant, insect, and birds) are already present in the country, some of them officially declared as invasive, but their import has not been restricted (Sohrabi et al. 2017; GISD 2020). The most recent account on naturalized and invasive alien flora of the world lists 79 naturalized plants in Iran, of which 13 are reported as invasive (Pyšek et al. 2017). Unfortunately, information on which alien plants currently present in the country are the most important in terms of impact on, and damage to local ecosystems is lacking. The impact scoring system provides a helpful tool to compare and prioritize alien plants.

This work thus aims to produce as complete as a possible list, based on current knowledge, of the most threatening alien plants in Iran using the Generic Impact Scoring System (GISS; Nentwig et al. 2010, 2016) and Environmental Impact Classification for Alien Taxa (EICAT; Blackburn et al. 2014). Using both schemes will increase the results' robustness by combining different focuses of the two scoring systems. These results will help raise awareness of the harmful alien plants in Iran, thus providing a rigorous scientific basis for import regulations at the border and effective management to minimize their negative impacts.

Methods

Data

We selected alien species in Iran for the scoring of their impacts based on information in published studies, GISD (The Global Invasive Species Database, http://www.iucngisd.org), preliminary lists, reports from agricultural and natural resources centers, and current observations by weed scientists, ecologists, and botanists (Dorjee et al. 2020). We also considered information on the history of species as invaders in other parts of the world to assess their potential for becoming invasive in Iran and consulted the literature on their impacts elsewhere (see Table S1 for the data sources used). This screening yielded 27 species alien to Iran that were analysed in this study.

A review of published literature was then undertaken to collate information on the reported potential impacts of each of these species, considering all regions that a given species has invaded, i.e., not restricting the search to Iran. As it was not possible to assess the impacts solely based on literature related to Iran, due to the lack of data, we also included information from other regions where the species' impact was studied. As the impact may differ regionally (Jeschke et al. 2014), our assessment includes both the impacts known to occur in our study region and those that can be expected based on the given species' behaviour in other regions where it is invasive. The term ''potential impact'' (maximal score found anywhere in the invaded range) is used as an indicator of future impact and a reasonable basis for management based on the precautionary principle (Rumlerová et al. 2016). For each species, the information about its impact was searched in (1) Web of Science (Clarivate Analytics), by using the species' scientific name combined with keywords indicating its alien/invasive status and impact categories as defined in GISS and EICAT; (2) bibliographic sources of information, including regional and national case studies and books (Sohrabi et al. 2017; Zand et al. 2017); (3) databases of invasive species with impacts recorded, namely CABI (Invasive

Species Compendium, www.cabi.org), GISD, USDA, and BioNET-EAFRINET. The literature search was performed in English and Persian.

Impact assessment protocol

Here we apply these two impact-scoring systems to alien plants in Iran. GISS separates IAS's impacts into environmental and socioeconomic, with each group divided into six different categories (Nentwig et al. 2016). Each species on our list was assessed for its impact in the 12 categories for which data were available. In each of these categories, we classified impact on a six-degree scale reflecting impact intensity. The scores range from 0 (no impact) to 5 (major impact). We differentiated the studies that addressed the impact of a species but did not record any (zero impact) from the situation when no data is available to score the impact of a given species in a given category (no data).

For EICAT, we scored the impact following guidelines for each of the 12 mechanisms (Hawkins et al. 2015, see also https://www.iucn.org/news/species/202009/iucn-standard-support-global-action-invasive-alien-species) to one of the following five categories, depending on their severity: minimal concern (MC), minor (MN), moderate (MO), major (MR) or massive (MV) (Blackburn et al. 2014). Information on each species' impact was recorded for all mechanisms where data was available. Following the EICAT guidelines for assigning the final impact score, we used the category with the highest score, i.e., the most severe impact. Confidence ratings of 'high,' 'medium' or 'low' were assigned to each assessment to quantify uncertainty about the correct classification (Hawkins et al. 2015).

The process of assessment for individual species was based on two step procedure when the first author of this study did initial scoring that was then revised by the last author who provided further comments on the scoring. If the first and second scoring differed, the references were checked and the final scoring was then made based on consensus.

Statistical analyses

To analyze the impacts of the 27 species assessed by GISS, we calculated the "logarithmic sum" of all values scored across the six categories ($\log_{10}$ (Σ(10^impact values)) for each species and impact group (environmental, socioeconomic). The logarithmic sum was used to reflect the exponential nature of the gradual increase in the GISS levels when individual levels of impact are of a different order of magnitude (Rumlerová et al. 2016).

To analyze the impacts of the 27 species assessed by EICAT, we ranked the species according to their maximum impact scored regardless of the category (method MAX) (Blackburn et al. 2014; Evans et al. 2016). The observed and expected distributions of impact magnitudes across mechanisms (25 species used) and plant form (herbaceous and woody species) were analyzed using contingency table tests (Fisher's exact test for count data; McDonald 2014). Impact categories were combined to produce two groups: 'lower tier' impacts, consisting of impacts classified as MC and MN, and 'upper tier' impacts, consisting of impacts classified as MO, MR, and MV. Impact mechanisms included competition, poisoning/toxicity, the transmission of disease, and chemical, physical or structural changes to invaded ecosystems. We did not use other mechanisms for Fisher's exact test due to zero records for some of the mechanisms. All analyses were carried out using R (R Core Team 2015). The percent of uncertainty was weighted as high, medium, and low confidence.

Comparison between GISS and EICAT protocols

For comparison between the GISS vs. EICAT, we rescaled the data for each category (GISS) and mechanism (EICAT) to range between 0 and 1. This was done by calculating (V – Vmin)/(Vmax – Vmin), where V represents the species impact score, and min and max refer to the minimum and maximum scores in each impact assessment scheme. For EICAT, high, medium, and low certainty was included in the calculation by multiplying the score by 1.0, 0.5 and 0.2, respectively (Turbé et al. 2017).

Results

The 27 species studied belong to 19 families, with Fabaceae having the highest frequency (six species). In terms of life history and life form, the data set included 20 perennial and seven annual species. Life form included three aquatic plants, three vines, two perennial grasses, one cactus, six trees, and two shrubs (Table 1).

Impact scoring with GISS

For the species assessed (Table 1), the logarithmic sum of scores ranged from 4.55 to 2.16. The top five alien plants (*Eichhornia crassipes, Ailanthus altissima, Imperata cylindrica, Amsinckia menziesii,* and *Paulownia fortunei*) had the greatest potential impact according to the total score. Two species (*Dalbergia sissoo* and *Sesuvium portulacastrum*) had minor potential impacts with scores of 2.16 and 3.12, respectively. Based on the environmental impact, the top alien species were *E. crassipes*, *A. altissima*, *Eupatorium cannabinum*, *I. cylindrica,* and *Pueraria montana*. However, according to socioeconomic impact, the five top listed species were *Robinia pseudoacacia*, *E. crassipes*, *A. altissima*, *I. cylindrica,* and *Euphorbia maculata.* The percentage of no data available differed by categries and species. *Dalbergia sissoo, Ammannia coccinea,* and *Sesuvium portulacastrum* are species with the greatest lack of data per category; for each of these species, seven out of 12 categories (58.3%) could not be scored due to lack of data (Table 1).

Comparing impact groups, *Eupatorium cannabinum* and *Canna indica* had higher environmental impacts than socioeconomic, while *Robinia pseudoacacia* and *Ipomoea purpurea* had higher socioeconomic impacts than environmental impacts. Based on the difference between logarithmic sums, four species had the same score across categories of environmental and socioeconomic impacts: *Pistia stratiotes*, *Merremia dissecta*, *Cynanchum acutum,* and *Ulex europaeus* (Fig. 1). Competition with other species (category 1.3), ecosystem impacts (category 1.6), and hybridization (category 1.5) scored highest among the environmental impacts, and the former two were also most frequent among the 27 species assessed. Some of the impacts are rarely recorded, namely transmission of diseases (category 1.4) and hybridization (category 1.5) with native species (Fig. 2).

EICAT

According to EICAT, *U. europaeus*, *Ambrosia psilostachya*, *E. crassipes*, *A. altissima,* and *A. menziesii* were the five species with major impact (Table 1). There were 16 species (59%) with moderate impacts, five with a minor, and two of minimal concern (Table. 1). About 44% and 22% of the most severe impact assignments were for competition and chemical impact, respectively (Fig. 3). In contrast, no impacts were assigned for predation, grazing/herbivory/browsing, and interaction with other alien species. Of all impact assignments, regardless of severity, 85%, 70%, and 55% were for competition, chemical, and poisoning impact, respectively. More 'upper tier' (MO, MR, and MV) were allocated for competition and poisoning/toxicity. *Sesuvium portulacastrum* and *Proboscidea fragrans* had minimal concern (MC) impact and could be classified as a non-problematic alien plant.

Impact magnitudes were also randomly distributed across impact mechanisms ($P = 0.83$) and life form ($P = 0.67$) (Table 2). Confidence ratings were randomly distributed across impact mechanisms ($P = 0.23$) and impact magnitudes ($P = 0.082$). Expected values for 'upper tier' (MO, MR, and MV) impacts across medium confidence were lower than observed values, but across low confidence the expected value was higher (Table 3). This means that high impact scores assigned with low confidence overestimated the impact and as the confidence of the assessor increased, it tended to underestimate the impact.

Comparison between EICAT and environmental impacts by GISS

From five species with maximum recorded impacts by EICAT, *E. crassipes,* and *A. altissima* also had high scores for environmental impact in GISS. *Azolla filiculoides*, *Cynanchum acutum*, *Robinia pseudoacacia*, *Prosopis juliflora,* and *Acacia saligna* ranked similarly according to the two scoring schemes. *Ulex europaeus*, *A. psilostachya* with major and *Euphorbia maculata* with minor impact in EICAT ranked differently in the two schemes, and so did *Z. mauritiana* and *Eupatorium cannabinum* (Table 1 and Fig. 4).

Table 1 Results of impact assessment of alien species in Iran by Generic Impact Scoring System (GISS) and Environmental Impact Classification for Alien Taxa (EICAT). Number of studies show the total number of analysed studies; numbers in brackets show studies from Iran. No data show percentage of GISS categories and EICAT mechanisms for which no data is available

Species	Family	Common name	Life form	Number of studies	GISS				EICAT			
					Environmental impact	Socioeconomic impact	Total impact	No data (%)	Impact mechanism	Maximum impact category	Confidence rating	No data (%)
*Eichhornia crassipes**	Pontederiaceae	Water hyacinth	AH	11 (3)	4.34	4.14	4.55	25	**bio-F**, comp, chem, pois	MR	Medium	50
*Ailanthus altissima**	Simaroubaceae	Tree of heaven	T	16 (4)	4.34	4.11	4.54	16.6	**pois**, chem	MR	High	20
*Eupatorium cannabinum**	Asteraceae	Hemp-agrimony	H	8 (0)	4.32	2.5	4.33	16.6	**comp**, pois, chem	MO	Low	70
*Imperata cylindrica**	Poaceae	Cogongrass	G	10 (2)	4.14	4.08	4.41	0	**comp**, pois,trans, chem, struc	MO	Medium	50
Pueraria montana var. *lobata**	Fabaceae	Kudzu	H	6 (0)	4.11	3.36	4.18	8.3	**comp**, chem, trans	MO	Medium	50
*Amsinckia menziesii**	Boraginaceae	Fiddleneck	H	9 (3)	4.11	4.04	4.38	25	**pois**, comp, hybr	MR	Medium	50
Anoda cristata	Malvaceae	Anoda	H	8 (2)	4.08	3.08	4.13	0	**comp**	MO	Medium	50
Ziziphus mauritiana	Rhamnaceae	Chinese date	S	8 (1)	4.08	3.3	4.15	16.6	**hybr**, chem, comp,	MO	Low	70
Paulownia fortunei	Paulowniaceae	Empress tree	T	10 (2)	4.07	4.05	4.36	16.6	**chem**, comp, pois, trans	MO	Medium	50
Canna indica	Cannaceae	Wild canna lily	H	8 (1)	4.01	2.34	4.02	25	**trans**, comp, pois	MO	Low	70
*Euphorbia maculate**	Euphorbiaceae	Prostrate spurge	H	11 (5)	3.69	4.08	4.23	8.3	**pois**, comp, chem	MN	Medium	50
*Azolla filiculoides**	Azollaceae	Mosquito fern	F	10 (3)	3.6	3.48	3.84	25	**struc**, chem, bio-f, comp	MO	Medium	50
Ulex europaeus	Fabaceae	Common gorse	S	12 (0)	3.5	3.49	3.8	0	**comp**, pois, chem, hybr, trans	MR	Medium	50
*Ambrosia psilostachya**	Asteraceae	Western ragweed	H	10 (2)	3.49	3.51	3.8	16.6	**comp**, pois, chemi	MR	High	20
*Cynanchum acutum**	Apocynaceae	Swallowworts	V	15 (6)	3.49	3.49	3.79	16.6	**comp**, trans, pois, chem	MO	Low	70
Robinia pseudoacacia	Fabaceae	Black locust	T	11 (2)	3.49	4.3	4.12	25	**trans**, comp, pois, chem	MO	low	70
*Prosopis juliflora**	Fabaceae	Mesquite	T	10 (4)	3.48	3.08	4.23	0	**pois**, chem, comp	MO	Medium	50

Table 1 continued

Species	Family	Common name	Life form	Number of studies	GISS				EICAT			
					Environmental impact	Socioeconomic impact	Total impact	No data (%)	Impact mechanism	Maximum impact category	Confidence rating	No data (%)
Acacia saligna	Fabaceae	Golden wreath wattle	T	11 (1)	3.48	3.08	3.62	8.3	**struc**, trans, pois, comp	MO	Medium	50
Ammannia coccinea	Lythraceae	Purple ammannia	H	15 (1)	3.47	3.04	3.61	41.6	**comp**	MN	Low	70
Opuntia ficus-indica	Cactaceae	Prickly pear	C	6 (0)	3.34	2.12	3.36	33.3	**chem**	MN	Medium	50
Merremia dissecta	Convolvulaceae	Alamo vine	V	8 (2)	3.32	3.32	3.62	25	**comp**	MN	Low	70
*Ipomoea purpurea**	Convolvulaceae	Tall morning-glory	V	12 (1)	3.3	4.08	4.14	8.3	**comp**, hybr	MO	Medium	50
Bambusa vulgaris	Poaceae	Common bamboo	G	11 (0)	3.3	4	4.08	25	**comp**, chem	MO	Medium	50
Pistia stratiotes	Araceae	Water lettuce	H	12 (1)	3.14	3.14	3.44	16.6	**chem**, bio-f, pois, trans	MO	Medium	50
Sesuvium portulacastrum	Aizoaceae	Sea purslane	H	9 (1)	3.08	2.05	3.12	41.6	**comp**, chem	MC	Low	70
Proboscidea fragrans	Martyniaceae	Ram's horn	H	4 (1)	3.01	3.32	3.49	25	**chem**	MC	High	20
Dalbergia sissoo	Fabaceae	Indian rosewood	T	9 (0)	2.08	1.38	2.16	58.3	**chem**, pois, comp	MN	Low	70

The measure used for GISS is the logarithmic sum of scores across environmental and socioeconomic impacts. For EICAT the following impact mechanisms are considered: *comp* competition, *hybr* hybridization, *pois* poisoning/toxicity, dise, transmission of disease to native species; *bio-f* bio-fouling, *chem* chemical impact on ecosystem; *struc* structural impact on ecosystem. The impact mechanism given in bold indicates the most severe impact. Impact categories: *MC* Minimal Concern, *MN* Minor, *MO* Moderatem, *MR* Major, *MV* Massive. The total number of studies on which assessment was based is given for each species and the % of categories in GISS for which no data are available. Species are ranked according to the total impact score in GISS. Life form: *H* herb, *T* tree, *S* shrub, *V* vine, *AH* aquatic herb, *G* grass, and *C* cactus. species. * = known as an invasive plant in Iran (Sohrabi et al. 2016; Zand et al. 2017)

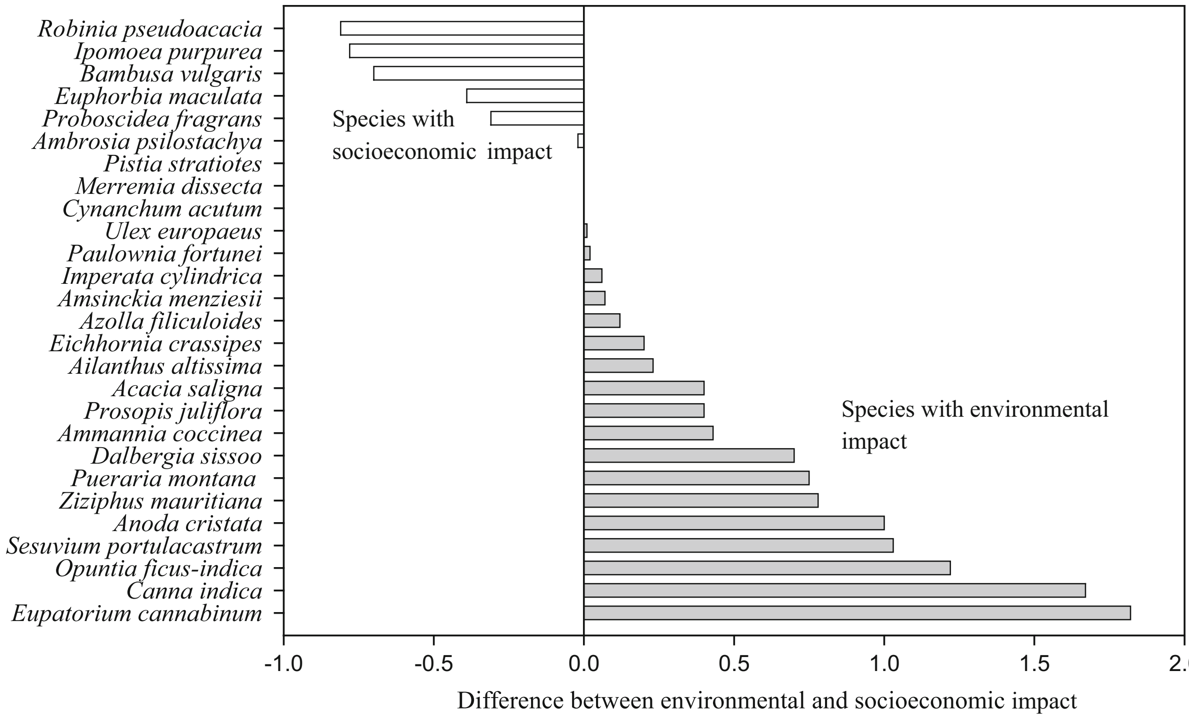

Fig. 1 Alien species ranked according to the difference between the logarithmic sum of all impact scores across categories of environmental (grey bars) and socioeconomic (white bars) impacts. Positive differences indicate species with higher environmnental compared to socioeconomic impact and vice versa. See methods for details

Discussion

GISS

The logarithmic sum of scores captures the species' impacts and the overall magnitude of potential threats, providing robust information for prioritization in a given country. Our results indicate that some specific traits, such as the aquatic life form, being toxic, perennial growth, and producing allergenic pollen, are associated with high socioeconomic impacts. *Eichhornia crassipes* as an aquatic and toxic plant (Bagheri et al. 2019), *A. menziesii* and *Euphorbia maculata* as toxic plants (Sohrabi et al. 2016), *I. cylindrica* as a perennial and noxious weed (Sohrabi et al. 2020), *A. altissima* and *Prosopis juliflora* as producers of allergenic pollen (Mousavi et al. 2017; Assarehzadegan et al. 2015) have the highest potential impacts at the country scale. More than half of the studied species are herbaceous, with environmental impacts manifested through competition with native species, and socioeconomic through reducing agricultural production. The relation between plant traits and the magnitude of impacts was reported for aquatic species *Elodea canadensis* or *E. crassipes* (Rumlerova et al. 2016). *Acacia dealbata*, as a legume, has the ability to seed prolifically and produce root suckers, while *Lantana camara* is poisonous to livestock and a host for numerous pests and diseases (Nentwig et al. 2018). Turbé et al. (2017) stated that two categories, competition and agricultural damage, in GISS had a large effect on the final score due to more studies and information on assessing impacts in these categories. Rumlerová et al. (2016) reported that the total logarithmic sum for environmental and socioeconomic groups provides a robust measure for identifying species with the highest overall potential impacts in Europe. In our study, while *A. menziesii* had lower scores in each impact group than some other species, the sum of the environmental and socioeconomic scores ranked it as one of the species with highest potential impact. Assessing the environmental and socioeconomic impacts separately, the categories that justify the prioritization of management measures can be better determined. Depending on priorities, environmental and socioeconomic impacts can be

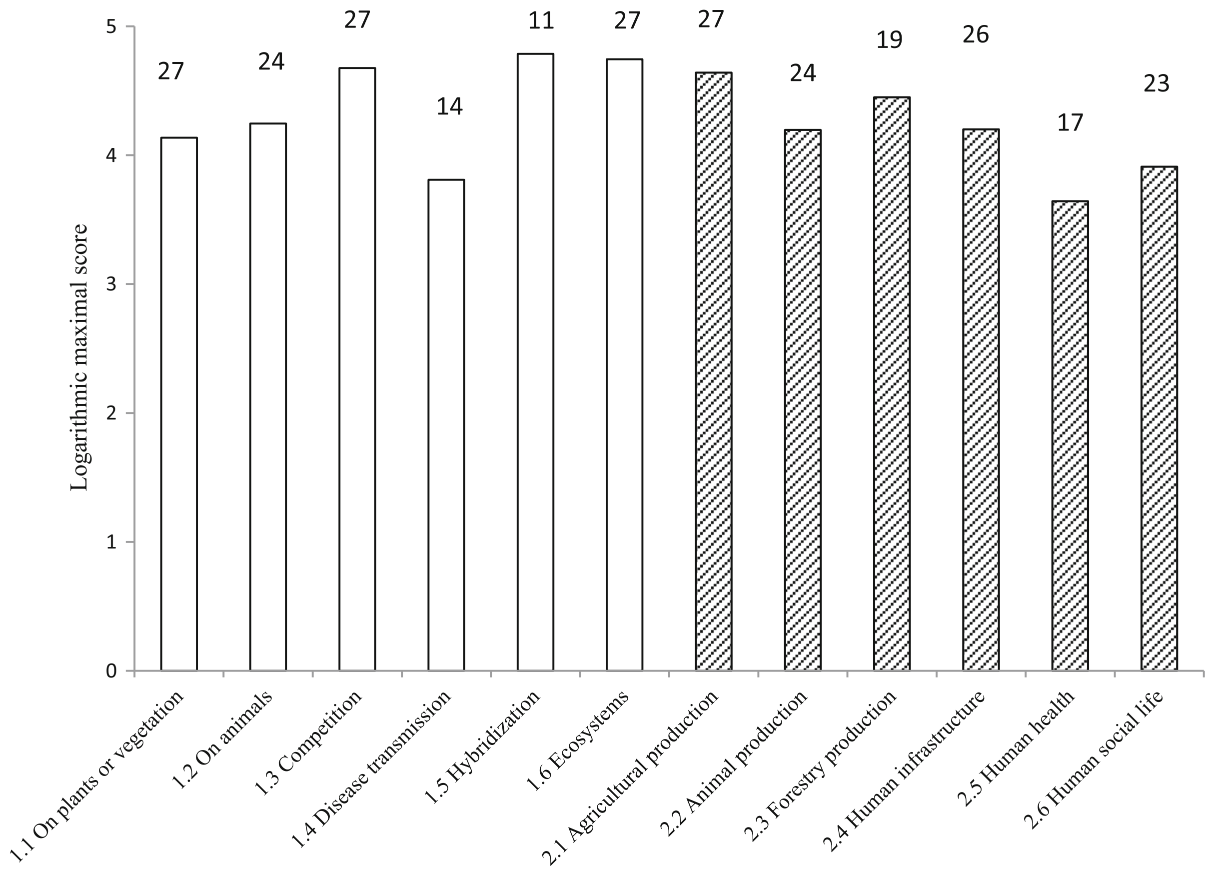

Fig. 2 Mean impact (based on the logarithmic maximal scores per species) for categories of environmental (white bars) and socioeconomic (hatched bars) impacts. The numbers of species (out of the 27 assessed) for which impacts in the given category were recorded are shown on top of the respective bar

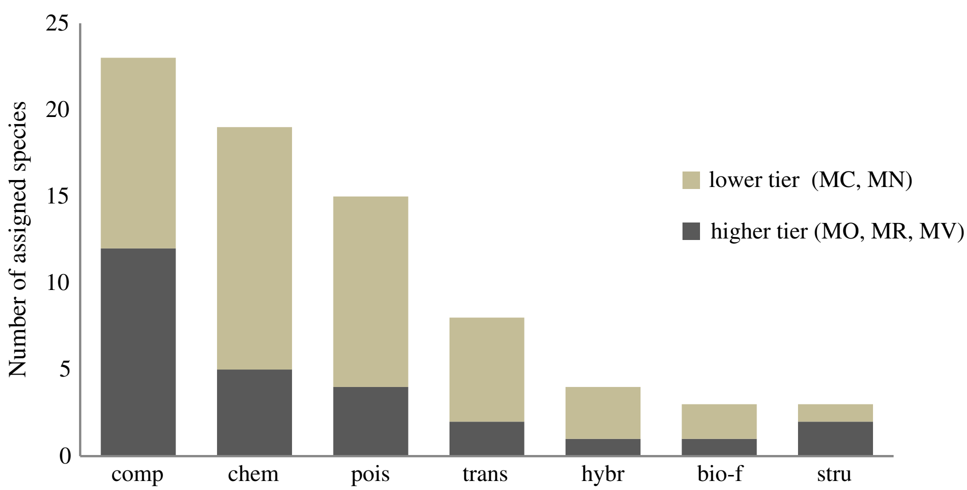

Fig. 3 The number of species assigned to each EICAT impact mechanism. comp, competition; pois, poisoning/toxicity; chem, chemical impact on ecosystem; trans, transmission of disease to native species; stru, structural impact on ecosystem; hybr, hybridization; bio-f, bio-fouling. Different colors indicate the severity of impact mechanism

Table 2 Contingency table (Fisher's exact test for count data) showing observed and expected numbers of impact allocations in EICAT to 'lower tier' (MC and MN) and 'upper tier' (MO, MR and MV) impact categories for each impact mechanism (most severe impact), and life forms

Impact mechanism	Lower tier (MC and MN)	Upper tier (MO, MR and MV)	Number of species with the impact mechanism
Competition	3 (3.36)	9 (8.64)	12
Poisoning/toxicity	1 (1.12)	3 (2.88)	4
Structural/chemical impact	3 (1.96)	4 (5.04)	7
Transmission of diseases	0 (0.56)	2 (1.44)	2
Total species	7	18	25
Life form			2-tail *P*-value
Herbaceous	6 (5.33)	12 (12.7)	0.67
Woody	2 (2.67)	7 (6.33)	
Total species	8	19	27

Expected values are displayed in parentheses. *P*-value for impact mechanisms = 0.83 and for life form = 0.67

Table 3 Contingency table showing observed and expected numbers of 'low', 'medium' and 'high' confidence assessments allocated to (a): each impact mechanism (most severe impact) with *p*-value = 0.23 (Fisher's exact test for count data); and (b): 'lower tier' (MC and MN) and 'upper tier' (MO, MR and MV) impact categories

	No. of 'low' confidence assessments	No. of 'medium' confidence assessments	No. of 'high' confidence assessments	Total confidence assessment allocations
(a)				
Competition	5 (3.84)	6 (6.72)	1 (1.44)	12
Poisoning/toxicity	0 (1.28)	3 (2.24)	1 (0.48)	4
Structural/chemical impact	1 (2.24)	5 (3.92)	1 (0.84)	7
Transmission of diseases	2 (0.64)	0 (1.12)	0 (0.24)	2
Total impact mechanism	8	14	3	25
(b)				
Lower tier	5 (2.67)	2 (4.44)	1 (0.88)	8
Upper tier	4 (6.33)	13 (10.16)	2 (2.11)	19
Total impact category	8	16	3	27

Expected values are displayed in (parentheses) with *P*-value = 0.082

separated (Nentwig et al. 2016). Of the six top alien species, ranked separately by environmental and socioeconomic impacts, four species had different rankings. The highest socioeconomic impacts were recorded for *Robinia pseudoacacia*, *Euphorbia maculata*, *Paulownia* sp., and *Ipomoea purpurea* and differed from their recorded environmental impacts. The focus of numerous studies on weedy aspects of *Ipomoea purpurea* and *Euphorbia maculata* in Iran may have resulted in them being ranked higher for socioeconomic impacts. The negative impact of *Robinia pseudoacacia* and *Bambusa vulgaris* on forest growth affected scores for socioeconomic impacts. The recorded environmental impacts were generally greater (16 species) than socioeconomic impacts (five species), which is likely the result of more attention

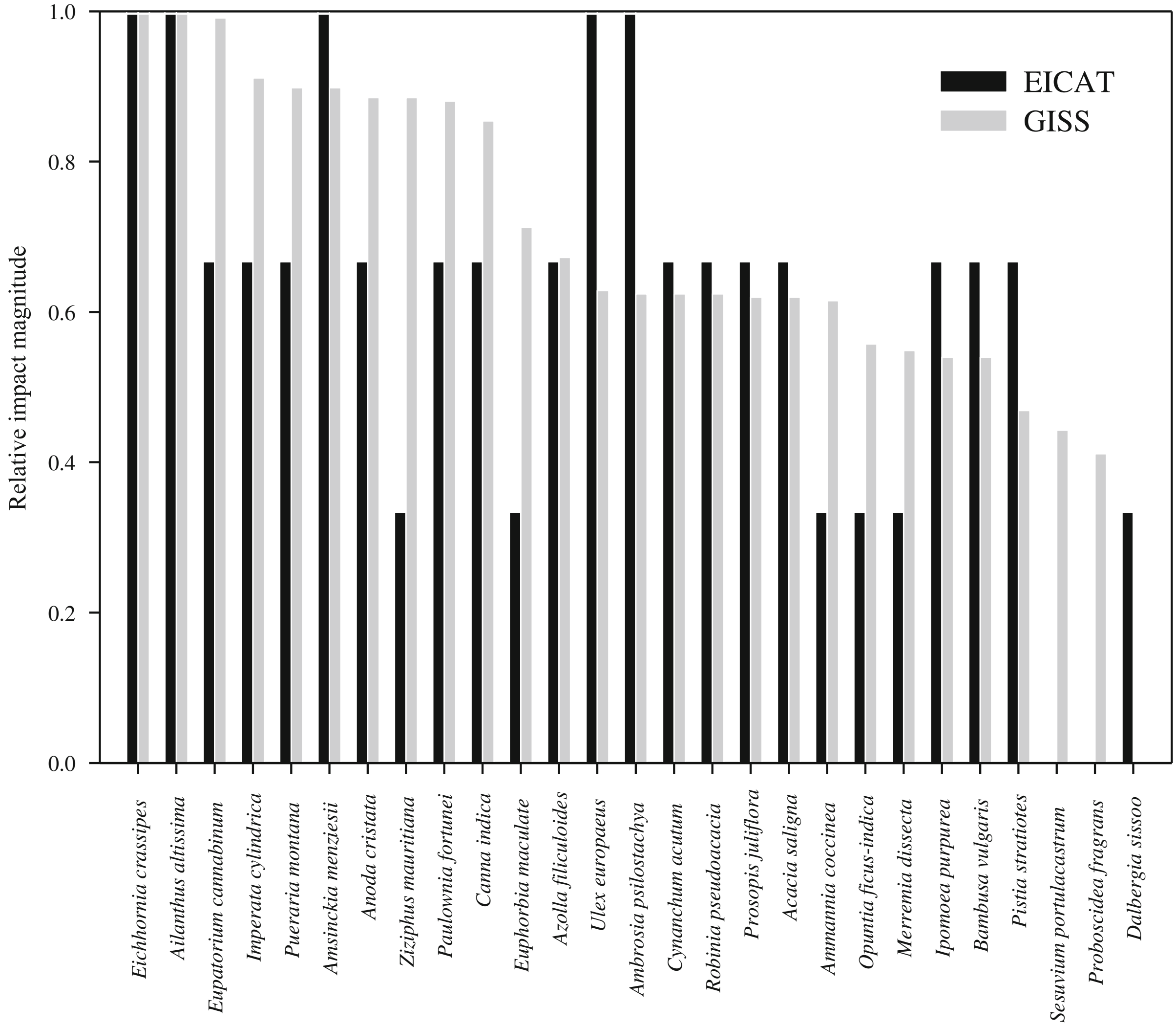

Fig. 4 Relationship between the impact scores of 27 alien species in Iran as obtained by the two scoring scheme, GISS (based on environmental impact) and EICAT. The scores were scaled to 0–1 for comparability

being paid to the study of environmental impacts, especially in Iran. Bacher et al. (2018) stated that for most amphibians species, no socioeconomic assessments are available.

EICAT

Our findings suggest that impact magnitudes assessed by EICAT give useful guidelines to determine the top priority species (*E. crassipes, A. altissima, A. menziesii, and U. europaeus*), and the scoring provides robust scientific support for future research activities and control programs. *Ulex europaeus* is extremely competitive (Atlan and Udo 2019), and *A. psilostachya* competes aggressively with grasses (Vermeire et al. 2005) and has major impacts on the habitats it invades. Impact ranking by magnitude helps distinguish between negative and extremely negative impacts (Bartz and Kowarik 2019).

Three mechanisms accounted for over 80% of environmental impacts: competition, poisoning/toxicity, and chemical impact on ecosystems. The dominance of competition might reflect that this mechanism is traditionally studied in ecology, and there is thus methodological know-how available. However, it is also frequently involved due to interaction between alien plants and native species—more alien plants compete with native plants for resources and space than transmit diseases or hybridize (Baker et al. 2008; Martin-Albarracin et al. 2015; Evans et al. 2016). In a study of transformer invasive alien species, Foxcroft et al. (2019) also found the direct competition to be the most frequently recorded impact. The Fabaceae, the most represented family in our study, includes invaders that change nutrient cycling and disturbance regimes, imposing chemical impact on the ecosystem. The importance of the allelopathic interaction (as weapons of evolutionarily increased competitive ability) in the success of invasive plants has been reported (Zheng et al. 2015), and indeed, more than half of the 27 plants exhibited an allelopathic effect, such as *E. crassipes* (Jin et al. 2003; Shanab et al. 2010), *I. cylindrica* (Susuki et al. 2018), *Ulex europaeus* (Pardo-Muras et al. 2018) and *Cynanchum acutum* (El-Demerdash et al. 2009; Faridmarandi et al. 2014).

Impact magnitudes were distributed randomly across the impact mechanisms and plant life forms. In general, in our study, the medium confidence category had a higher rating than low and high confidence. It may be attributed to limited available data for some of the mechanisms. Evans et al. (2016) stated that higher confidence in assessing alien birds was associated with clearly demonstrated impact and data availability. It appears that declaring the impact of alien plants as obvious is more complex than for other taxa such as birds due to the belowground processes (root systems and mycorrhizal networks, leaf litter impact, and soil chemistry or microbial communities) in plants that are more difficult to study (Marchante et al. 2009; Stricker et al. 2015; Cybill et al. 2020). The biggest challenge to the successful application of EICAT is the lack of impact data for most species (Evans et al. 2016). Our study can be considered a first step to direct research in alien plants in Iran towards improving the lack of impact data and confidence about assessments, and provides general species-specific information that can be used in other similar studies.

Comparing GISS and EICAT

Both GISS and EICAT emphasized the effect of competition and agricultural damage (Turbé et al. 2017), which makes them suitable tools for prioritizing alien species as invasive weeds to impose efficient management of agricultural areas. GISS is more comprehensive than EICAT in that it also considers socioeconomic impacts, but the overall classifications using the two schemes are relatively similar. Lower tier (MC and MN) and upper tier (MO, MR, and MV) impact categories according to EICAT correspond to GISS classification. Some differences in ranking of species may be related to the lack of literature to quantify impacts on complex ecosystem services in Iran or to the emphasis on the reversibility of impacts in EICAT, which is one of the key criteria to discriminate between massive and major impacts (Blackburn et al. 2014). Therefore, whether the affected resources can be restored is important in the classification by EICAT. For example, the reversibility of the toxic impact of *Euphorbia maculata* on co-occurring plants (Hilty 2009) or that of the hybridization impact of *Ziziphus mauritiana* has not been recorded (Asatry and Noemi 2013). Impact assessment protocols depend not only on scientific information about the intensity of environmental and socioeconomic impacts but also on their variability, persistence, and reversibility in space and time (Vilà et al. 2010). One of the potential benefits of the EICAT protocol is that it can identify knowledge gaps and direct future invasive alien species research (Evans et al. 2016). Turbé et al. (2017) stated that GISS and EICAT protocols were considered the easiest to use, probably because both schemes contained brief, self-contained guidance within each question. The questions were based on hierarchical statements specifying the context and reference situation. Vilà et al. (2019) mentioned the reversibility as one of the main criteria that contribute to EICAT being a successful impact assessment protocol.

Conclusions and management recommendations

The results presented here are important to facilitate the management and policy of biological invasions in Iran. We highlighted the top eight alien plants (*E. crassipes*, *A. altissima*, *U. europaeus*, *A. psilostachya*, *Prosopis juliflora*, *I. cylindrica*, *Euphorbia maculata,* and *A. menziesii*) that need to be prioritized and managed. Some species are highly persistent in the sites invaded and vigorously regenerating following the management treatment. Species such as *Dalbergia* *sissoo, Proboscidea fragrans,* and *Sesuvium portulacastrum* are unlikely to have negative impacts, but monitoring is necessary for possible future changes under different bioclimatic conditions. GISS and EICAT could be used to link patterns (which species have high or low impacts and are more likely to affect the environment or socioeconomy) to traits to understand and forecast species with different types of impact (Milanovic et al. 2020a, b). Obtaining more information on the type of impact of an invasive species will to reduce knowledge gaps and improve impact assessment outcomes. The role of rarely recorded impacts such as disease or hybridization with native species needs to be analysed properly, as their impact might be underestimated due to lack of data. Import regulations for the arrival of new species into the country and across provincial borders are important next steps.

Our work demonstrates that much remains to be done to better understand the environmental and especially socioeconomic impact of alien plants in Iran. Besides, the assessment of impacts is complicated because ecological and social contexts may change with time.

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