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Current status of alert alien species management for the establishment of proactive management systems in Korea

Seung Hun Son, A-Ram Jo and Dong Eon Kim* 

Abstract

Background: Some of the introduced alien species introduced settle, multiply, and spread to become invasive alien species (IAS) that threaten biodiversity. To prevent this, Korea and other countries legally designate and manage alien species that pose a risk to the environment. Moreover, 2160 alien species have been introduced in South Korea, of which 1826 animals and 334 plants are designated. The inflow of IAS can have negative effects such as ecosystem disturbance, habitat destruction, economic damage, and health damage to humans. To prevent damage caused by the inflow of IAS in advance, species that could potentially pose a risk to the environment if introduced in South Korea were designated as alert alien species (AAS).

Results: The designation criteria were in accordance with the “Act on the Conservation and Use of Biological Diversity” and the “Regulations on the Ecological Risk Assessment of AAS and IAS” by the National Institute of Ecology. The analysis result of risk and damage cases indicated that mammals affect predation, competition, human economic activity, virus infection, and parasite infection. Birds have been demonstrated to affect predation, competition, human economic activity, and health. It was indicated that plants intrude on the ecosystem by competing with native species with their high-population density and capacity to multiply and cause allergic inducement. Interestingly, 300 species, including 25 mammals, 7 birds, 84 fishes, 28 amphibians, 22 reptiles, 1 insect, 32 spiders, 1 mollusk, 1 arthropod, and 99 plants, are included in the list of AAS.

Conclusions: AAS designation plays a role in preventing the reduction of biodiversity by IAS in South Korea and preserving native species. Moreover, it is determined to provide considerable economic benefits by preventing socio-economic losses and ecological damage.

Keywords: Alert alien species, Biodiversity, Conservation, Invasive alien species, Risk assessment

Introduction

Alien species are introduced either intentionally or unintentionally around the world by human activities. Human activities have escalated due to the vitalization of overseas travel based on the increase in trade and transportation development between countries, etc., and this led to the increased spread of alien species (SCBD, 2014). The inflow of alien species in natural and semi-natural ecosystems has a negative effect on

the economy and social facilities (Bomford, 2008). Such influence will gradually accelerate, and the inflow of alien species will increase up to 20 times in 30 years, thus increasing the damage (Sardain et al., 2019). Furthermore, environmental problems caused by the indiscriminate use of resources by humans affect habitat fragmentation and climate change. These environmental problems disturb the ecosystem and affect the settlement and multiplication of alien species when they enter the native ecosystem (Sharp et al., 2011). The inflow of invasive alien species (IAS) makes the ecosystem more vulnerable and

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unhealthy, leading to a reduction of biodiversity (IUCN, 2000).

Although the damage caused by IAS among the developed and developing countries differs, all the countries signed the Convention on Biological Diversity to enhance the understanding of biodiversity due to the importance of public awareness in the matter. Moreover, Aichi Biodiversity Targets were selected for global biodiversity conservation from 2011 to 2020 (Junior et al., 2018). The management of alien species is one of the 20 detailed targets. It was reported that inflow pathways should be identified, and alien species that flow in shall be managed and controlled to prevent the inflow and settlement of alien species (SCBD, 2014). For this purpose, the International Union for Conservation of Nature (IUCN), an international organization, has published a list of representative IAS. However, it is difficult to manage the inflow of all alien species around the world through an international cooperation organization. Therefore, a list of alien species has been designated and managed on the national level by assessing the impact of alien species on the ecosystem or selecting the species that threaten the ecosystem (Koh et al., 2002; Cal-IPC., 2006; Gederaas et al., 2012).

In 2005, Japan began to designate IAS with the introduction of the “Invasive Alien Species Act (IAS Act).” In 2019, 145 species were designated as IAS, whereas others were designated and managed as Uncategorized Alien Species (UAS) or Living Organisms Required to have a Certificate Attached (LORCA) by their types (Kil et al., 2015). China manages 734 species through the “Chinese Biodiversity Conservation Action Plan” (Xu et al., 2012). The UK enacted the “Wildlife and Countryside Act” in 1981 to prevent the inflow of IAS. The “Great Britain Invasive Non-Native Species Strategy (GBNNS)” was established in 2013 based on the “Strategy for Controlling Invasive Species” developed by Great Britain Non-Native Species Secretariat in 2008. Based on this, 142 species are legally prohibited from entering the UK (GBNNS, 2016). The damage inflicted upon indigenous species by alien species is more critical in New Zealand compared with the continent as it comprises many islands. Therefore, New Zealand has been blocking the inflow of alien species as a precautionary measure (Department of Conservation, 1996; Brenton-Rule et al., 2016). Furthermore, the Biosecurity Act enacted in 1993 defines unwanted organisms to prevent the inflow of 969 species that are not on the Clean List (Ministry for primary industries n.d., 2016). The USA manages alien species with Clean List and Dirty List. In particular, the Dirty List prevents the inflow of alien

species under the Lacey Act and the Federal Noxious Weed Act (Congress U. S., 1993) and promotes integrated management of 2873 species designated by each state (US department of agriculture, 2010). The IUCN has announced 100 of the world’s worst IAS as targets for global management. Europe designated 503 species, NOBANIS designated 496 species, and Australia designated 563 species as IAS to prevent and manage the inflow by law (Table 1). Furthermore, 1109 alien species introduced in South Korea in 2011 doubled to 2160 in 2013 (Kil and Kim, 2014). IAS comprises various classifications, including mammals, birds, fish, amphibians, reptiles, insects, plants, and invertebrates (Ministry of Environment notification, 2017). The designation and management of alert alien species (AAS) were added to the Act on the Conservation and the Use of Biological diversity in 2019 to prevent the increasing inflow of alien species and reduce the damage caused by it. AAS are alien species that may cause disruption in the native ecosystem if introduced, and 300 species have been designated and announced currently.

This study introduces the status of laws and designations of IAS in Korea and highlights the “Act on the Conservation and the Use of Biological Diversity,” which manages AAS. We focused on analysis on (1) criteria of designating AAS and (2) impact of AAS on the ecosystem, socio-economy, and human health.

Material and methods

The Act on the Conservation and the Use of Biological Diversity of South Korea

The Act on the Conservation and the Use of Biological Diversity was first enacted in 2013 and amended in 2019. Article 2 (Definition) defines alien species as organisms that exist outside their place of origin or habitat after being artificially or naturally introduced from foreign countries. In addition, AAS is defined as a species, among alien species, that disturb or are likely to disturb the balance of the ecosystem. AAS are designated and managed under risk evaluation (Article 21-2), approval for Importation and Inbound transfer of Species of concern for Domestic Inflow (Article 22), and management of Species of Concern for Domestic Inflow (Article 22-2).

Procedure of designations related to Alien Species in South Korea

AAS are species that are judged to be harmful when alien species are introduced into the domestic ecosystem. To designate AAS, a list of alien species was made that have not been introduced into Korea. Alien species data was collected by ecological

Table 1 Status of invasive alien species to be prevented and managed by law

	IUCN	Japan	China	EU	NOBANIS	UK	Australia	New Zealand	USA
Mammals	14	25	10	43	26	7	75	52	29
Birds	8	24	35	45	46	35	8	15	119
Fishes	3	7	8	43	13	12	53	35	33
Amphibian	3	21	5	12	5	5	4	19	31
Reptile	2	14	3	18	9	2	12	3	69
Insect	17	21	252	15	102	30	4	133	489
Spider	0	7	0	0	0	0	0	6	0
Mollusca	4	4	25	36	22	3	0	37	31
Arthropod	3	5	16	21	46	7	0	11	25
Plant	37	16	337	264	113	28	407	658	2047
Others	9	1	63	6	114	13	0	0	4
Total	100	145	734	503	496	142	563	969	2877

characteristics, physiological characteristics, and harmful cases on the ecosystem, socio-economy, and human health. The committee evaluated the data collected according to AAS designation criteria. The AAS designation criteria are divided into four categories and the specific details (Table 2).

Results

Status of AAS designation

Three hundred species are designated and announced as AAS in South Korea. These include 25 mammals, 7 birds, 84 fish, 28 amphibians, 22 reptiles, 1 insect, 99 plants, and 34 invertebrates. Moreover, 15 species from the World’s Worst 100 IAS by IUCN are included, which comprises 4 mammals (*Herpestes auropunctatus*, *Herpestes javanicus*, *Sciurus carolinensis*, and *Mustela erminea*), 2 fish (*Gambusia affinis* and *Lates niloticus*), 1 amphibian (*Rhinella*(=*Bufo*) *marinus*), 1 reptile (*Boiga*

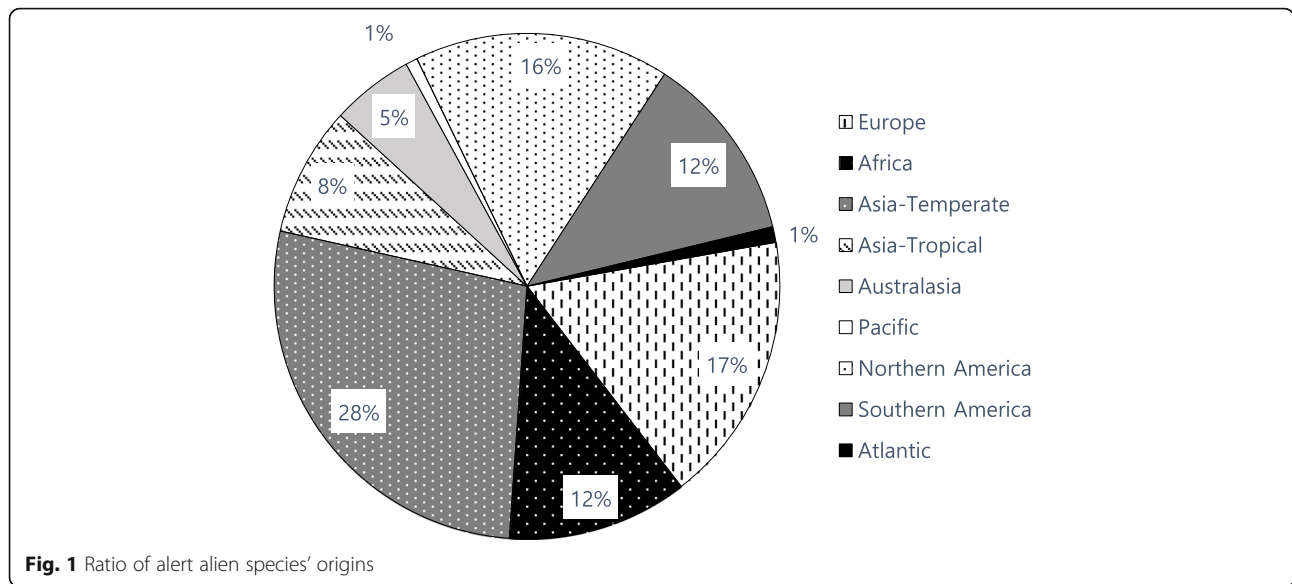
irregularis), 1 invertebrate (*Anoplolepis gracilipes*), and 6 plants (*Chromolaena odorata*, *Mikania micrantha*, *Sphagneticola trilobata*, *Prosopis glandulosa*, *Acacia mearnsii*, and *Ardisia elliptica*). Furthermore, 238 of the 300 AAS were indicated as species for legal management by foreign countries (Appendix 1).

Origin of AAS regional distribution

Nine regions were marked as the origin of 300 AAS using the world geographic scheme for recording plant distributions. The nine regions are Europe, Africa, Asia-Temperate, Asia-tropical, Australasia, Pacific, Northern America, Southern America, and Antarctic (Brummitt, 2001). The Asia-Temperate region reported for the largest proportion of the 300 species designated as AAS with 28%, followed by Europe with 17% and North America with 16%. Africa and South America were 12% each and Asia-tropical was 8% (Fig. 1).

Table 2 Four categories and their specific details for designating AAS in South Korea

4 criteria of designating AAS	Specific details
Alien species that are globally recognized for their risks	Promotion of the designation of species recognized as harmful by international organizations such as IUCN’s World’s Worst IAS comprising 100 species Specify species for legal management by neighboring countries (such as China and Japan) and major trading partners (such as US and EU); prior review of species prohibited to import from other countries
Species that have caused social or ecological damage	Promotion of the designation of species that caused social damage such as human diseases and industrial damage Promotion of the designation of species that caused ecological harm through predation, hybridization, etc., of indigenous species
Species with genetic and ecological characteristics similar to existing IAS (30 species)	Promotion of the IAS designation of similar species expected to have increased demand due to the ballooning effects of IAS designation Promotion of the designation of a genus if there are several allied species with similar attributes
Species with a high probability of settlement due to habitat conditions being similar to those in South Korea	Promotion of the prioritized designation of species that are highly likely to spread due to their high fertility rate



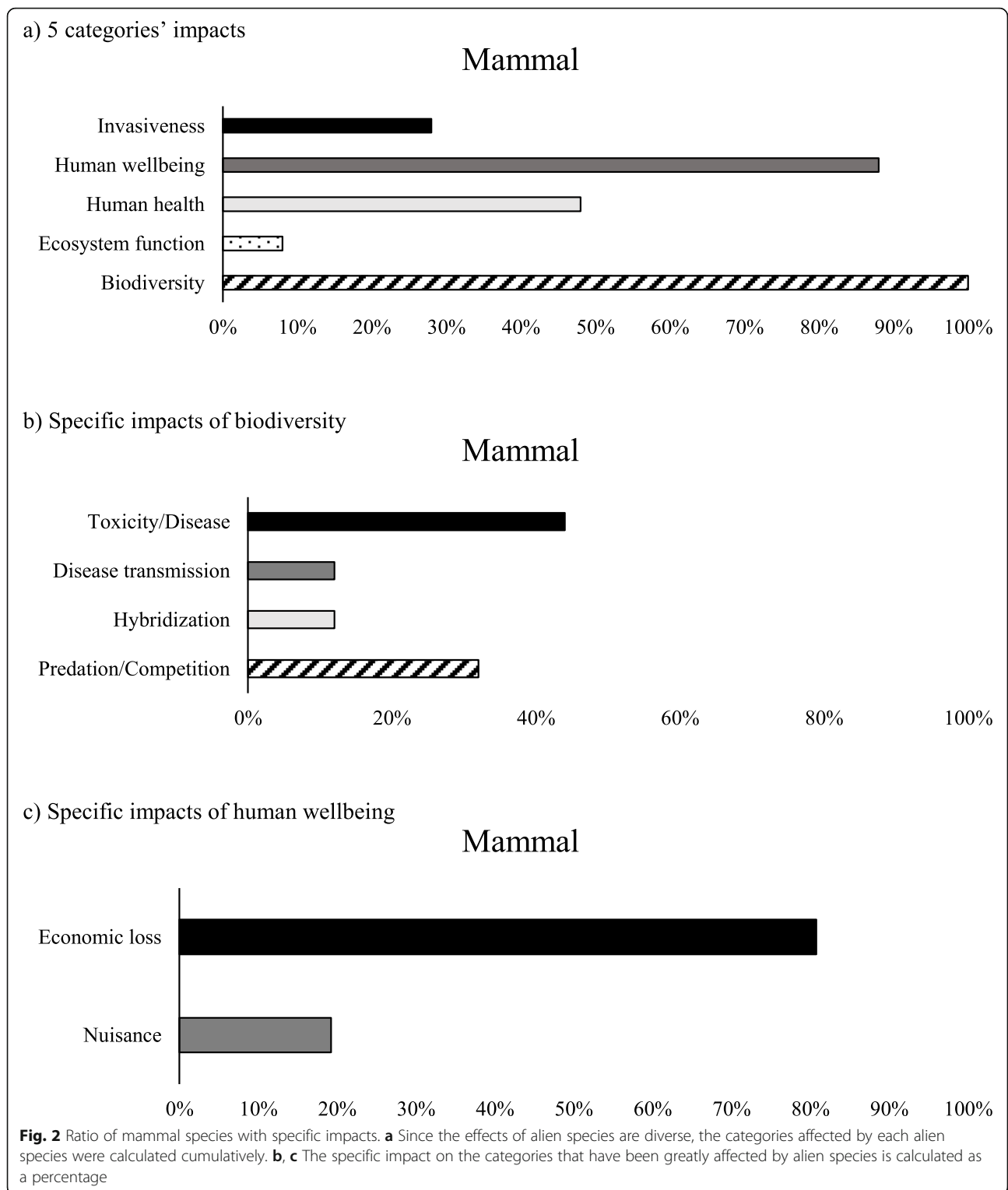
Analysis of AAS effect

The experts of each classification group assessed AAS in accordance with the “Ecological Risk Assessment of Invasive Alien Species and Designation of Alert Alien Species” from 2013 to 2019. The assessment was determined by combining scores and opinions on the impact of each species on the ecosystem, socio-economy, and human health. Species designated as AAS by the assessment were analyzed for their influence in each classification. The 5 categories of biodiversity, ecosystem function, invasiveness, human health, and human well-being were classified into detailed items. Biodiversity was classified into predation/competition, hybridization, disease transmission, and toxicity/disease. Ecosystem function was classified into nutrient cycle change, physical modification of habitat, disruption of ecosystem structure, destruction of important and/or protected habitat, and the increasing possibility of fire. Invasiveness

was classified into high-population density, adaptability, easy spread, possibility of introduction, and difficulty of control, etc. Human health was classified into disease transmission and poisoning/toxicity/injury. Human well-being comprises nuisance and economic loss (Table 3). Among the five categories, mammals appear to have considerable influence on biodiversity and human well-being. In biodiversity, it was analyzed to have an influence on the relations of disease and prediction/competition. Moreover, it had a strong impact on economic loss for human well-being (Fig. 2). It is believed that mammals adversely affect social and economic activities because they are prone to disease and spread diseases as a medium for zoonosis. Birds appear to have considerable influence on biodiversity, human well-being, and invasiveness, which affect prediction/competition in biodiversity. Human well-being affects economic loss. Invasiveness was analyzed to affect high-population

Table 3 Effect of alert alien species on five categories and specific impacts

	Category impacts				
	Biodiversity	Ecosystem function	Invasiveness	Human health	Human wellbeing
Specific impacts	Predation/Competition	Nutrient cycle change	High population density	Disease transmission	Nuisance
	Hybridization	Physical modification of the habitat	Adaptation	Poisoning/Toxicity/Injury	Economic loss
	Disease transmission	Disruption of ecosystem structure	Easily spreading		
	Toxicity/Disease	Destruction of important, protected habitat	Possibility of introduction		
		Increasing possibility of fire	Difficulty of control		



density and easy spread (Fig. 3). Efforts and expenses are required to control the inflow of birds due to their high proliferation and ability to easily spread infectious diseases. Fish and reptiles had considerable influence on biodiversity. In the detailed items of

biodiversity, fish were explained to affect predation/competition, hybridization, and toxicity/disease. Reptiles were reported to have a significant impact on the relations of predation/competition (Figs. 4 and 5). It has been found that the inflow of fish causes

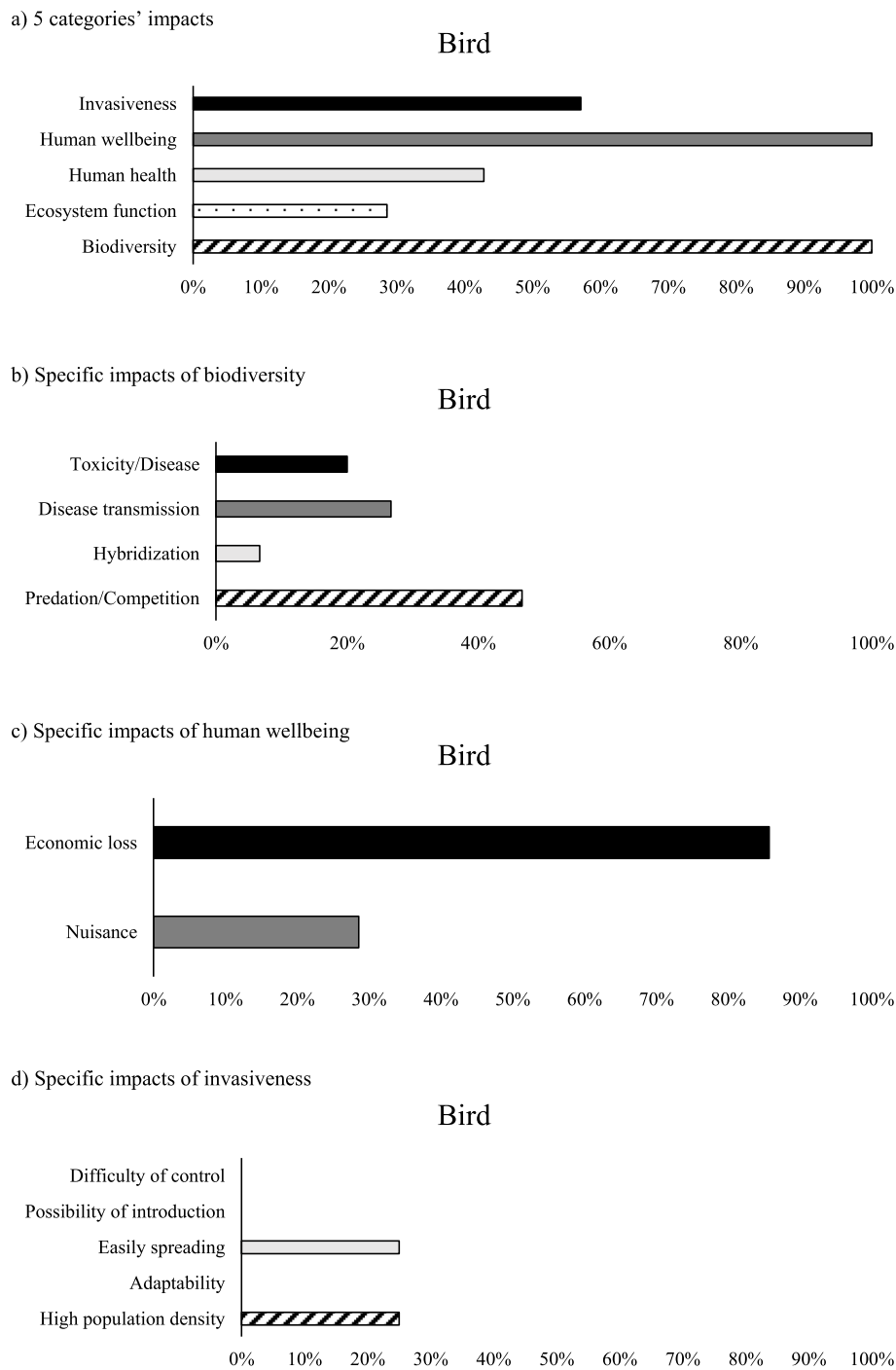
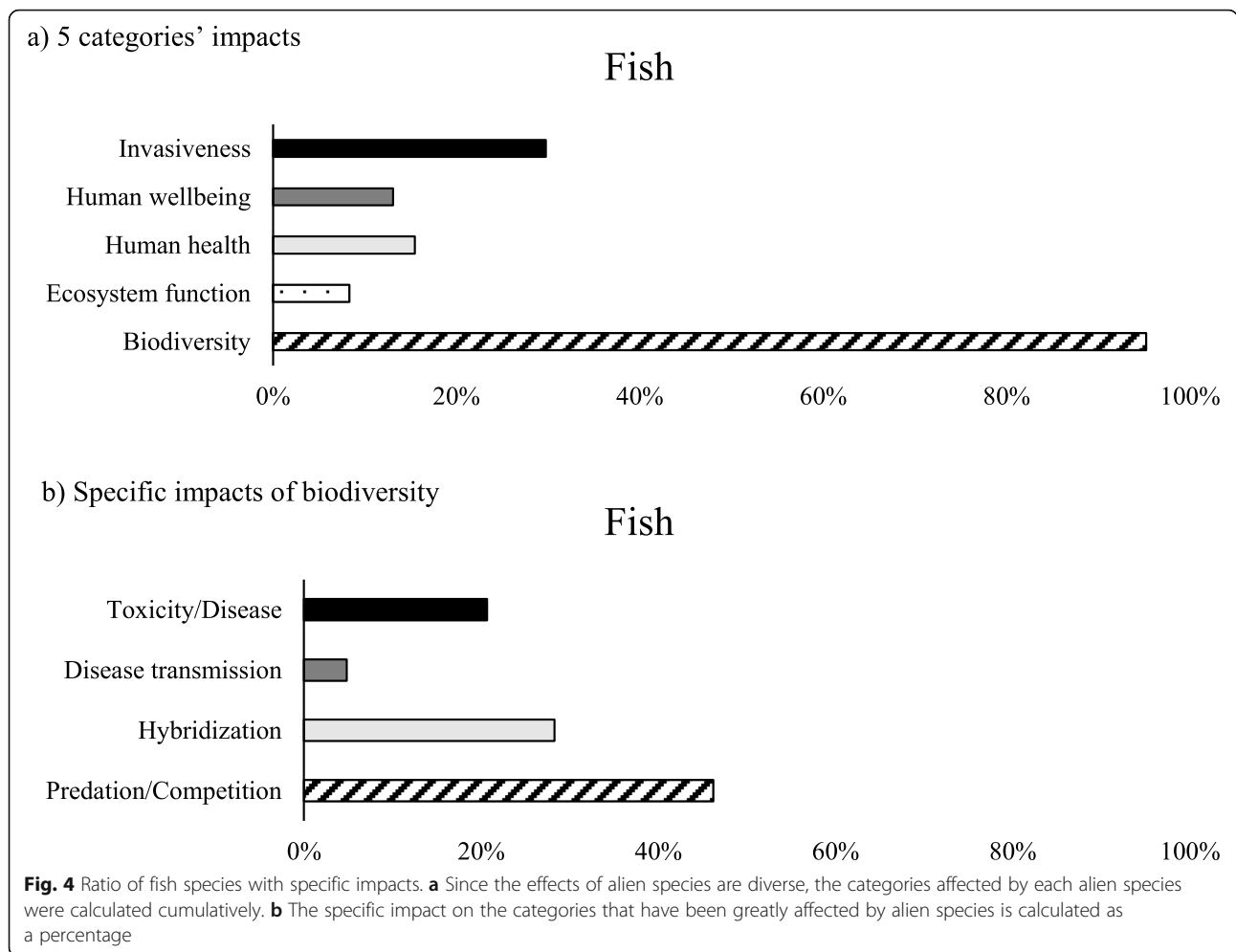


Fig. 3 Ratio of bird species with specific impacts. **a** Since the effects of alien species are diverse, the categories affected by each alien species were calculated cumulatively. **b, c, d** The specific impact on the categories that have been greatly affected by alien species is calculated as a percentage

hybridization with native species and damage, leading to the reduction of native species and biodiversity. Amphibians have been demonstrated to have a considerable impact on biodiversity and invasiveness. They were analyzed to considerably impact

predation/competition in biodiversity and on easy spread and adaptability in invasiveness (Fig. 6). Plants were reported to have considerable influence on biodiversity. It was analyzed to have a strong effect on invasiveness compared with other

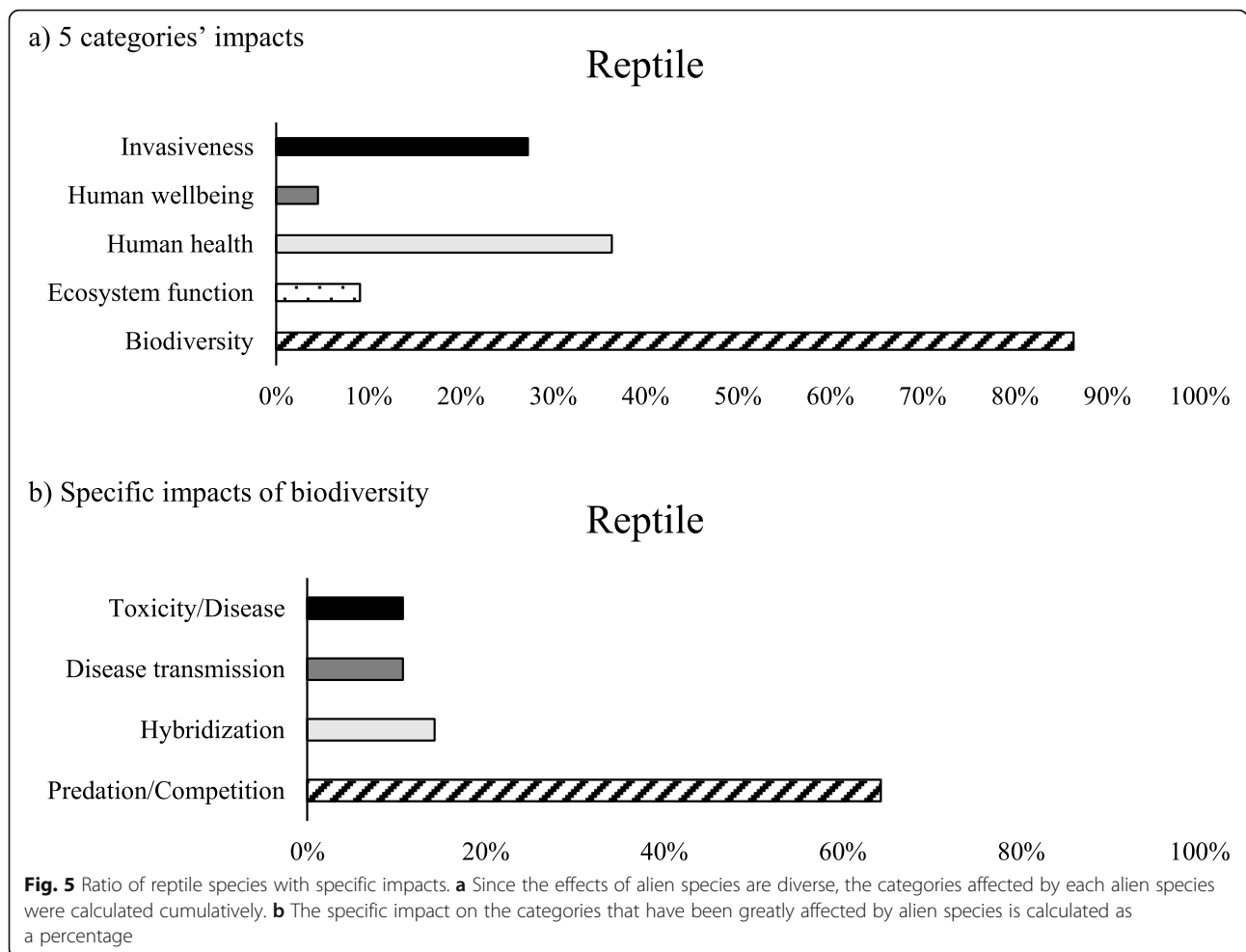


classifications and on human well-being. In biodiversity, plants have been demonstrated to affect predation/competition and toxicity/disease. They affected high-population density and easy spread of invasiveness and economic loss in human well-being (Fig. 7). When plants are flowed in, they form flora and rapidly spread to compete with native species. It is known that alien plants that win against native plants destroy the habitat environment and affect other species living in their habitats. All classifications were identified to influence the relations of predation/competition in the biodiversity category. Predation affects the population sizes of alien and native species, and competition is caused due to the utilization of resources such as habitat and food.

Discussion

If alien species are flowed in, multiply, and settle, expenses and effort are required for control and management. Luque (2014) reported that the total cost borne by each country to effectively prevent the inflow of alien species from around the world is >\$300

billion per year. In Australia, the European fox (*Vulpes vulpes*) has affected native plants, thus causing damage amounting to ~\$190 million a year (McLeod, 2004). The European carp (*Cyprinus carpio*) affected the ecosystem, thus reducing the biodiversity of native fish, plants, and invertebrates; the damage amount was reported to be ~\$11.8 million a year (McLeod, 2004). It is reported that the damage in EU was ~€12 billion a year (European Commission, 2014; Kettunen et al., 2008), that in the USA was \$8.7 billion from 2010 to 2013, and that in Japan was >¥1 billion from 2007 to 2012 (Ministry of Environment, 2014). To efficiently reduce the cost of preventing and managing alien species, it is necessary to designate AAS and block the species in advance. Moreover, the inclusion of AAS in the quarantine system for export and import trade goods at airports and ports will strictly prevent the inflow of AAS. Moreover, if relevant ministries cooperate to preemptively prevent AAS from the customs' entry in the face of a steady increase in the inflow of alien species into the country, it is believed to effectively reduce control



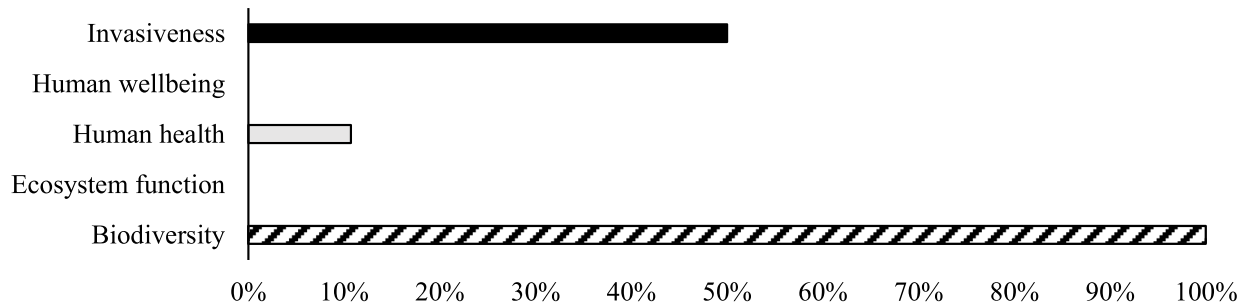
and management costs related to alien species. By comparing the origin and distribution status of AAS with the foreign trade bureau (import), the government can draw up a list of countries that require more thorough quarantine during the importing process. This is believed to rigorously prevent the inflow of AAS. In South Korea, AAS has been designated and officially announced since 2019 with the revision of the Act on the Conservation and the Use of Biological Diversity. To add and facilitate the list of AAS in the future, the AAS designation process needs to be more systematized. In particular, to enhance the system for preventing alien species, the pathway of alien species should be identified to block the intentional inflow and reduce the unintentional inflow. Furthermore, it is important to identify species that can adapt to the current climate zone. Since habitable species easily settle and multiply if they flow in, the process of collecting information on characteristics of alien species by climate group shall be strengthened.

Conclusion

This study was conducted to analyze the effects of AAS on the environment, economy, and human. The designation of AAS has an influence on preventing the reduction of biodiversity and preserving native species. In addition, it provided considerable economic benefits by preventing socio-economic losses and ecological damage. However, the AAS assessment system currently used in South Korea is slightly different from the revised law. Hence, the assessment system shall be supplemented in accordance with the law by assessing the AAS that have been enlisted to date. It seems necessary to supplement the AAS assessment system with a scientific and systematic assessment system by actively accepting various foreign assessment systems such as AquaNIS, EFSA, ENSARS, EPPO, FISK, GABLIS, GB NNRA, GISS, EICAT, and NORWAY SCHEME. Furthermore, to prevent damage by IAS that have been identified globally, a system should be placed into practice to prevent the inflow of suspected species by broadly designating AAS as a precautionary measure and aim for early detection.

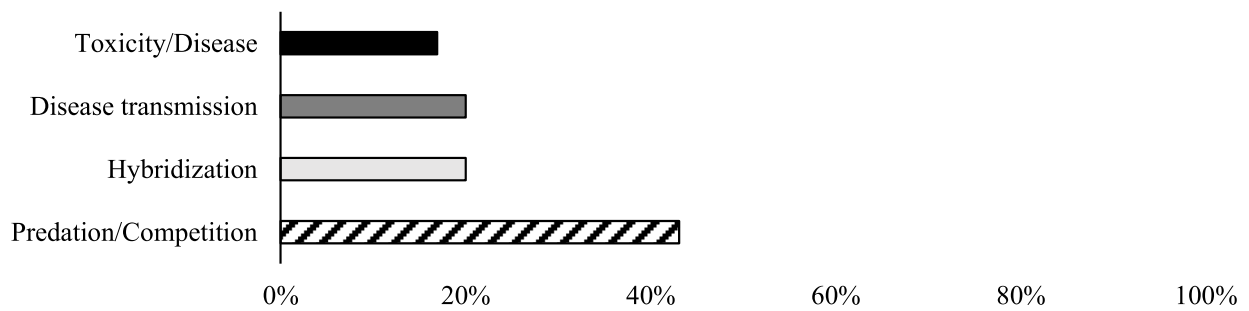
a) 5 categories' impacts

Amphibian



b) Specific impacts of biodiversity

Amphibian



c) Specific impacts of invasiveness

Amphibian

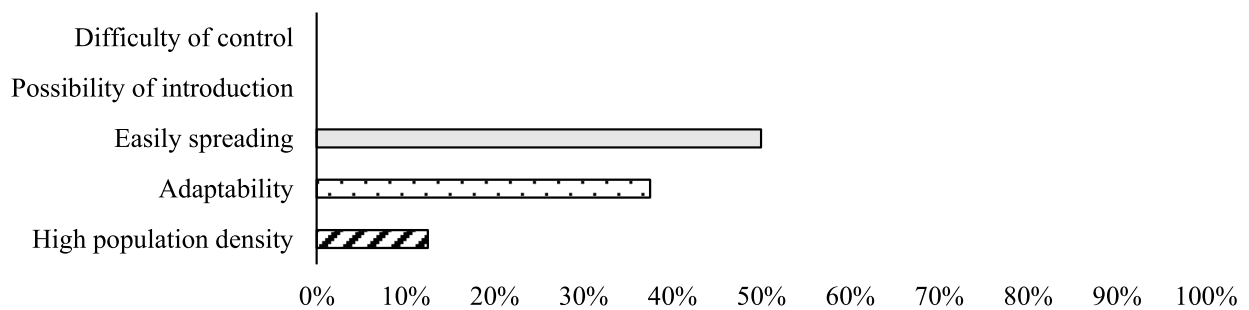
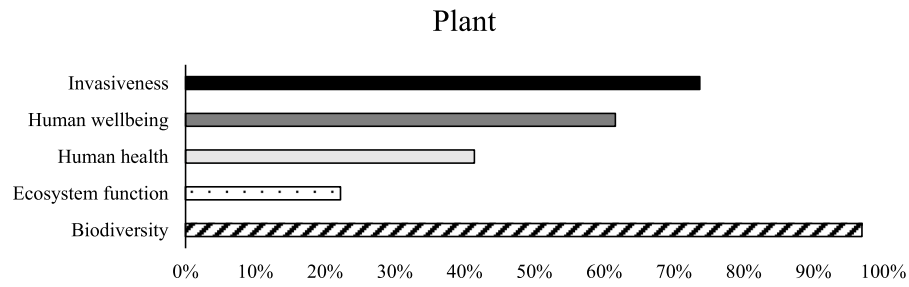
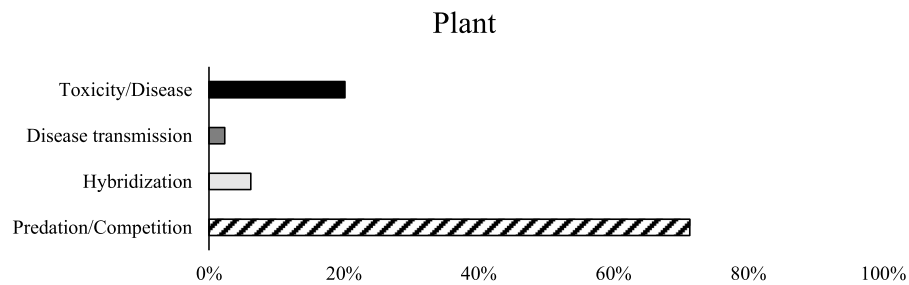


Fig. 6 Ratio of amphibian species with specific impacts. **a** Since the effects of alien species are diverse, the categories affected by each alien species were calculated cumulatively. **b, c** The specific impact on the categories that have been greatly affected by alien species is calculated as a percentage

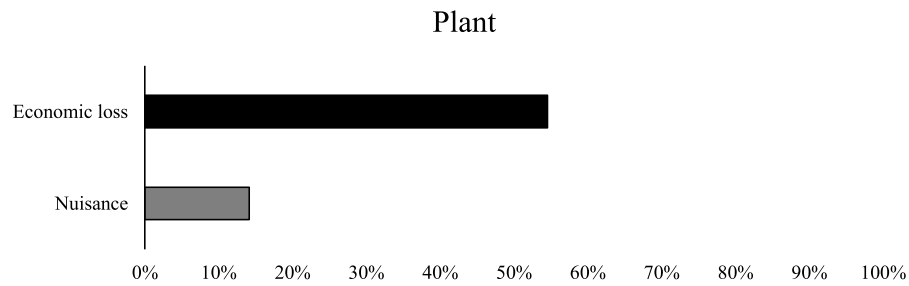
a) 5 categories' impacts



b) Specific impacts of biodiversity



c) Specific impacts of human wellbeing



d) Specific impacts of invasiveness

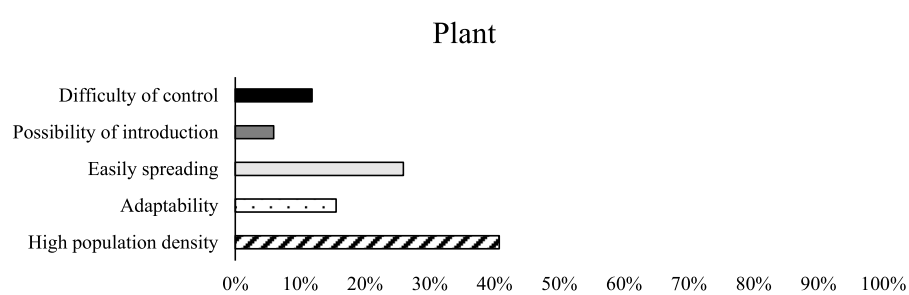


Fig. 7 Ratio of plant species with specific impacts. **a** Since the effects of alien species are diverse, the categories affected by each alien species were calculated cumulatively. **b, c, d** The specific impact on the categories that have been greatly affected by alien species is calculated as a percentage

Appendix 1

Table 4 List of alert alien species in Republic of Korea

No.	Group	Scientific name	Listed in
1	Mammal	<i>Rattus exulans</i>	Australia
2		<i>Peromyscus maniculatus</i>	
3		<i>Callosciurus finlaysonii</i>	Japan, Europe
4		<i>Herpestes auropunctatus</i>	IUCN, Japan
5		<i>Sciurus aureogaster</i>	Japan, USA
6		<i>Glis glis</i>	UK
7		<i>Castor fiber</i>	
8		<i>Odocoileus virginianus</i>	New Zealand
9		<i>Sus scrofa vittatus</i>	Europe
10		<i>Lepus californicus</i>	USA
11		<i>Herpestes javanicus</i>	IUCN, Japan, Europe
12		<i>Sciurus carolinensis</i>	IUCN, Japan, Europe
13		<i>Mustela erminea</i>	IUCN, New Zealand
14		<i>Dasypus novemcinctus</i>	
15		<i>Mustela vison</i>	Japan, Europe, UK
16		<i>Atelerix albiventris</i>	Japan
17		<i>Chlorocebus aethiops</i>	
18		<i>Dasyprocta leporina</i>	USA
19		<i>Desmodus rotundus</i>	
20		<i>Eliomys quercinus</i>	
21		<i>Epomops franqueti</i>	
22		<i>Hypsignathus monstrosus</i>	
23		<i>Ovis orientalis</i>	
24		<i>Puma yagouaroundi</i>	USA
25		<i>Callosciurus erythraeus</i>	Japan, Europe
26	Bird	<i>Acridotheres tristis</i>	IUCN, USA, Australia, New Zealand, Europe
27		<i>Passer domesticus</i>	Australia, New Zealand, USA
28		<i>Phasianus versicolor</i>	
29		<i>Pycnonotus jocosus</i>	Japan, Australia, USA
30		<i>Streptopelia chinensis</i>	Australia
31		<i>Carpodacus mexicanus</i>	USA
32		<i>Corvus splendens</i>	Europe, UK, Australia, USA
33	Fish	<i>Micropterus dolomieu</i>	Japan
34		<i>Siniperca chuatsi</i>	Japan
35		<i>Gambusia affinis</i>	IUCN, Japan, China, Europe, New Zealand, USA
36		<i>Esox lucius</i>	Japan
37		<i>Channa striata</i>	USA
38		<i>Neogobius melanostomus</i>	Japan, Europe, USA
39		<i>Perca fluviatilis</i>	Japan, China, New Zealand, USA
40		<i>Clarias gariepinus</i>	China, Europe
41		<i>Piaractus brachypomus</i>	China, USA
42		<i>Pygocentrus nattereri</i>	China, USA
43		<i>Atractosteus spatula</i>	Japan

Table 4 List of alert alien species in Republic of Korea (Continued)

No.	Group	Scientific name	Listed in
44		<i>Phractocephalus hemiliopterus</i>	
45		<i>Maccullochella peelii</i>	Japan
46		<i>Alosa sapidissima</i>	
47		<i>Alosa pseudoharengus</i>	USA
48		<i>Amia calva</i>	USA
49		<i>Sander lucioperca</i>	Japan, Europe, USA
50		<i>Ictiobus cyprinellus</i>	China
51		<i>Ictiobus niger</i>	Europe
52		<i>Labeo rohita</i>	China
53		<i>Lepomis cyanellus</i>	Japan, USA
54		<i>Lepomis megalotis</i>	Japan
55		<i>Micropterus punctulatus</i>	Japan, USA
56		<i>Misgurnus fossilis</i>	
57		<i>Mylopharyngodon piceus</i>	China
58		<i>Paramisgurnus dabryanus</i>	
59		<i>Perccottus glenii</i>	Europe, USA
60		<i>Petromyzon marinus</i>	
61		<i>Pylodictis olivaris</i>	Japan, Europe, USA
62		<i>Salmo salar</i>	China, Europe
63		<i>Silurus glanis</i>	Japan, USA
64		<i>Ameiurus nebulosus</i>	Japan, Europe, New Zealand
65		<i>Ameiurus melas</i>	Japan, Europe
66		<i>Morone americana</i>	Japan, USA
67		<i>Morone chrysops</i>	Japan, USA
68		<i>Scardinius erythrophthalmus</i>	New Zealand, USA
69		<i>Acheilognathus tabira erythropterus</i>	Japan
70		<i>Aspius aspius</i>	
71		<i>Biwia zezera</i>	
72		<i>Gnathopogon elongatus elongatus</i>	
73		<i>Ischikauia steenackeri</i>	
74		<i>Ictiobus bubalus</i>	
75		<i>Esox niger</i>	Japan
76		<i>Gasterosteus microcephalus</i>	
77		<i>Oncorhynchus masou rhodurus</i>	
78		<i>Oncorhynchus clarkii</i>	
79		<i>Catostomus Catostomus</i>	
80		<i>Cobitis biwae</i>	
81		<i>Acheilognathus asmussii</i>	Japan
82		<i>Carassius gibelio</i>	USA
83		<i>Squalius cephalus</i>	
84		<i>Leuciscus leuciscus</i>	
85		<i>Sarcocheilichthys variegatus microoculus</i>	
86		<i>Lepomis humilis</i>	Japan, USA
87		<i>Channa panaw</i>	

Table 4 List of alert alien species in Republic of Korea (Continued)

No.	Group	Scientific name	Listed in
88		<i>Sander volgensis</i>	Japan
89		<i>Liobagrus reini</i>	
90		<i>Lates niloticus</i>	IUCN, Japan, USA
91		<i>Morone saxatilis</i>	Japan, China
92		<i>Gymnocephalus cernua</i>	Japan, USA
93		<i>Leuciscus idus</i>	New Zealand, USA
94		<i>Alburnus alburnus</i>	USA
95		<i>Alburnus chalcoides</i>	
96		<i>Coregonus albula</i>	USA
97		<i>Coregonus lavaretus</i>	USA
98		<i>Coregonus maraena</i>	USA
99		<i>Coregonus peled</i>	USA
100		<i>Gambusia holbrooki</i>	Japan, Europe, Australia, USA
101		<i>Ictalurus furcatus</i>	USA, Japan
102		<i>Pterygoplichthys disjunctivus</i>	USA
103		<i>Pterygoplichthys multiradiatus</i>	
104		<i>Rutilus rutilus</i>	USA
105		<i>Cyprinus carpio</i> var. <i>specularis</i>	
106		<i>Parachondrostoma toxostoma</i>	Europe
107		<i>Amphilophus citrinellus</i>	USA
108		<i>Clupeonella tscharchalensis</i>	Europe
109		<i>Cobitis bilineata</i>	Europe
110		<i>Knipowitschia longicaudata</i>	Europe
111		<i>Neogobius eurycephalus</i>	Japan, Europe
112		<i>Neogobius fluviatilis</i>	Japan, Europe
113		<i>Neogobius gorlap</i>	Japan, Europe
114		<i>Neogobius pallasi</i>	Japan, Europe
115		<i>Odontesthes bonariensis</i>	USA
116		<i>Siganus rivulatus</i>	Europe
117	Mollusca	<i>Perna viridis</i>	USA
118	Arthropoda	<i>Procambarus fallax</i>	Japan, Europe, USA
119	Amphibian	<i>Osteopilus septentrionalis</i>	Japan, USA
120		<i>Xenopus laevis</i>	Europe, UK, USA
121		<i>Rana ridibundus</i>	Europe, UK
122		<i>Rana lessonae</i>	
123		<i>Bufo japonicus formosus</i>	Japan
124		<i>Bufo japonicus japonicus</i>	Japan
125		<i>Fejervarya kawamurai</i>	
126		<i>Fejervarya sakishimensis</i>	
127		<i>Rana japonica</i>	
128		<i>Pelophylax porosus</i>	
129		<i>Epidalea calamita</i>	Japan
130		<i>Sclerophrys mauritanica</i>	
131		<i>Rhinella marina</i>	IUCN, Japan, Europe, Australia, USA

Table 4 List of alert alien species in Republic of Korea (Continued)

No.	Group	Scientific name	Listed in
132		<i>Pelophylax esculentus</i>	
133		<i>Pelophylax kurtmuelleri</i>	
134		<i>Anaxyrus cognatus</i>	Japan
135		<i>Anaxyrus punctatus</i>	Japan
136		<i>Cryptobranchus alleganiensis</i>	
137		<i>Duttaphrynus melanostictus</i>	Japan, USA
138		<i>Rana grylio</i>	Japan, China
139		<i>Rana heckscheri</i>	Japan, China
140		<i>Rana pipiens</i>	
141		<i>Hylarana erythraea</i>	
142		<i>Hoplobatrachus tigerinus</i>	
143		<i>Hoplobatrachus rugulosus</i>	
144		<i>Litoria dentata</i>	Australia
145		<i>Litoria ewingii</i>	New Zealand
146		<i>Litoria raniformis</i>	New Zealand
147	Reptile	<i>Boiga irregularis</i>	IUCN, Japan, Europe, USA
148		<i>Graptemys pseudogeographica</i>	Europe, USA
149		<i>Vipera aspis</i>	
150		<i>Mauremys mutica</i>	Japan
151		<i>Graptemys geographica</i>	
152		<i>Mauremys caspica</i>	Japan
153		<i>Pelomedusa subrufa</i>	
154		<i>Darevskia armeniaca</i>	
155		<i>Eutropis multifasciata</i>	
156		<i>Calotes mystaceus</i>	USA
157		<i>Calotes versicolor</i>	USA
158		<i>Protobothrops mucrosquamatus</i>	Japan
159		<i>Boiga cyanea</i>	Japan
160		<i>Rhabdophis subminiatus</i>	
161		<i>Boiga cynodon</i>	Japan
162		<i>Boiga nigriceps</i>	Japan
163		<i>Notechis scutatus</i>	Australia
164		<i>Epicrates maurus</i>	USA
165		<i>Ctenotus lanceolini</i>	Australia
166		<i>Lampropholis delicata</i>	New Zealand
167		<i>Mauremys sinensis</i> × <i>Mauremys reevesii</i>	Japan
168		<i>Mauremys japonica</i> × <i>Mauremys reevesii</i>	Japan
169	Insect	<i>Anoplolepis gracilipes</i>	IUCN, New Zealand
170	Spider	<i>Atrax robustus</i>	Japan
171		<i>Latrodectus antheratus</i>	Japan
172		<i>Latrodectus apicalis</i>	Japan
173		<i>Latrodectus bishopi</i>	Japan
174		<i>Latrodectus cinctus</i>	Japan
175		<i>Latrodectus corallinus</i>	Japan

Table 4 List of alert alien species in Republic of Korea (Continued)

No.	Group	Scientific name	Listed in
176		<i>Latrodectus curacaviensis</i>	Japan
177		<i>Latrodectus dahli</i>	Japan
178		<i>Latrodectus diaguia</i>	Japan
179		<i>Latrodectus elegans</i>	Japan
180		<i>Latrodectus erythromelas</i>	Japan
181		<i>Latrodectus geometricus</i>	Japan
182		<i>Latrodectus hasselti</i>	Japan
183		<i>Latrodectus hesperus</i>	Japan
184		<i>Latrodectus hystrix</i>	Japan
185		<i>Latrodectus indistinctus</i>	Japan
186		<i>Latrodectus karrooensis</i>	Japan
187		<i>Latrodectus katipo</i>	Japan
188		<i>Latrodectus liliana</i>	Japan
189		<i>Latrodectus mactans</i>	Japan
190		<i>Latrodectus menavodi</i>	Japan
191		<i>Latrodectus mirabilis</i>	Japan
192		<i>Latrodectus obscurior</i>	Japan
193		<i>Latrodectus pallidus</i>	Japan
194		<i>Latrodectus quartus</i>	Japan
195		<i>Latrodectus renivulvatus</i>	Japan
196		<i>Latrodectus revivensis</i>	Japan
197		<i>Latrodectus rhodesiensis</i>	Japan
198		<i>Latrodectus thoracicus</i>	Japan
199		<i>Latrodectus tredecimguttatus</i>	Japan
200		<i>Latrodectus variegatus</i>	Japan
201		<i>Latrodectus</i>	Japan
202	Plant	<i>Vincetoxicum rossicum</i>	
203		<i>Carduus acanthoides</i>	USA
204		<i>Carduus tenuiflorus</i>	USA, Australia
205		<i>Chromolaena odorata</i>	IUCN, China, Europe, Australia, USA
206		<i>Mikania micrantha</i>	IUCN, Japan, Australia, China, USA
207		<i>Senecio madagascariensis</i>	Japan, USA, Australia
208		<i>Sphagneticola trilobata</i>	IUCN, USA, China
209		<i>Cenchrus echinatus</i>	China, Australia, USA
210		<i>Neyraudia reynaudiana</i>	USA
211		<i>Brachiaria mutica</i>	China
212		<i>Vulpia bromoides</i>	USA
213		<i>Fallopia baldschuanica</i>	USA, UK
214		<i>Heracleum sosnowskyi</i>	Europe
215		<i>Hydrocotyle ranunculoides</i>	Japan, Europe, UK, Australia
216		<i>Asparagus asparagoides</i>	USA, Australia, New Zealand
217		<i>Landoltia punctata</i>	USA
218		<i>Elodea nuttallii</i>	Europe, UK
219		<i>Andropogon gayanus</i>	Australia

Table 4 List of alert alien species in Republic of Korea (Continued)

No.	Group	Scientific name	Listed in
220		<i>Oenanthe pimpinelloides</i>	Australia
221		<i>Ageratina riparia</i>	USA, Australia, New Zealand
222		<i>Onopordum acanthium</i>	USA
223		<i>Bunias orientalis</i>	Europe, USA
224		<i>Alternanthera pungens</i>	Japan, China, Australia
225		<i>Prosopis glandulosa</i>	IUCN, Europe
226		<i>Salpichroa origanifolia</i>	Australia
227		<i>Myriophyllum heterophyllum</i>	Japan, Europe, USA
228		<i>Salvinia minima</i>	USA
229		<i>Sagittaria graminea</i>	USA, Europe
230		<i>Centaurea diffusa</i>	USA
231		<i>Ehrharta erecta</i>	China, New Zealand, USA
232		<i>Lolium persicum</i>	China, Canada
233		<i>Paspalum conjugatum</i>	China, USA
234		<i>Hydrocharis morsus-ranae</i>	USA
235		<i>Stratiotes aloides</i>	USA, Australia
236		<i>Eichhornia azurea</i>	USA, Australia
237		<i>Monochoria hastata</i>	USA
238		<i>Aegilops tauschii</i>	China
239		<i>Setaria palmifolia</i>	New Zealand, USA
240		<i>Echinocystis lobata</i>	Europe, USA
241		<i>Lycium ferocissimum</i>	Australia, New Zealand, USA
242		<i>Paspalum fimbriatum</i>	China, USA
243		<i>Berteroa incana</i>	USA
244		<i>Lepidium appelianum</i>	
245		<i>Heteropogon contortus</i>	USA
246		<i>Spartina densiflora</i>	Japan, USA
247		<i>Centaurea stoebe</i> subsp. <i>micranthos</i>	Australia, USA
248		<i>Rhaponticum repens</i>	Australia, USA
249		<i>Myriophyllum alterniflorum</i>	Japan, USA
250		<i>Passiflora foetida</i>	China, USA
251		<i>Spartina patens</i>	Japan, USA
252		<i>Acacia paradoxa</i>	Australia, New Zealand, USA
253		<i>Alhagi maurorum</i>	Australia, USA, South Africa
254		<i>Arctotheca calendula</i>	New Zealand, USA
255		<i>Asparagus scandens</i>	Australia, New Zealand
256		<i>Buddleja madagascariensis</i>	New Zealand, USA, South Africa
257		<i>Carpobrotus chilensis</i>	New Zealand, USA
258		<i>Cenchrus spinifex</i>	Australia, USA
259		<i>Crupina vulgaris</i>	Australia, USA, Canada
260		<i>Dolichandra unguis-cati</i>	China, Europe, Australia, South Africa
261		<i>Echium vulgare</i>	USA, Australia, New Zealand
262		<i>Ehrharta longiflora</i>	New Zealand, USA
263		<i>Erica lusitanica</i>	Australia, New Zealand, Pacific islands

Table 4 List of alert alien species in Republic of Korea (Continued)

No.	Group	Scientific name	Listed in
264		<i>Erechtites valerianifolius</i>	China, USA, Pacific islands
265		<i>Euphorbia cyathophora</i>	USA, Pacific islands
266		<i>Flaveria bidentis</i>	China, South Africa
267		<i>Genista linifolia</i>	Australia, USA
268		<i>Genista monspessulana</i>	Australia, USA, Pacific islands, Hawaii
269		<i>Heliotropium europaeum</i>	Australia, China
270		<i>Hordeum bulbosum</i>	
271		<i>Hyptis brevipes</i>	China, Australia
272		<i>Hyptis suaveolens</i>	China, Australia, Hawaii, Guam, Papua New Guinea, Philippines, Singapore, Taiwan
273		<i>Ipomoea alba</i>	USA
274		<i>Iva axillaris</i>	Australia, USA
275		<i>Jatropha curcas</i>	China, Australia
276		<i>Lantana montevidensis</i>	China, Australia, New Zealand, USA, Hawaii
277		<i>Megathyrus maximus</i>	USA
278		<i>Morella faya</i>	Europe, Australia, Hawaii
279		<i>Pittosporum undulatum</i>	Australia, Europe, USA
280		<i>Rosa bracteata</i>	Europe, USA
281		<i>Senecio angulatus</i>	Japan, New Zealand
282		<i>Toxicodendron radicans</i>	Europe, Australia, USA
283		<i>Acacia auriculiformis</i>	USA, Singapore, Hawaii
284		<i>Acacia confusa</i>	
285		<i>Acacia farnesiana</i>	China
286		<i>Acacia mearnsii</i>	IUCN, New Zealand, South africa, Hawaii
287		<i>Agropyron desertorum</i>	
288		<i>Ardisia elliptica</i>	IUCN, Europe, Hawaii
289		<i>Amelanchier spicata</i>	Europe
290		<i>Bassia hyssopifolia</i>	
291		<i>Bromus rubens</i>	
292		<i>Centaurea melitensis</i>	
293		<i>Chrysanthemoides monilifera</i>	New Zealand
294		<i>Cortaderia jubata</i>	Europe, New Zealand, Hawaii, South africa
295		<i>Cytisus striatus</i>	
296		<i>Delairea odorata</i>	Australia
297		<i>Dioscorea oppositifolia</i>	
298		<i>Dittrichia graveolens</i>	Australia
299		<i>Galeopsis tetrahit</i>	Alaska
300		<i>Emex spinosa</i>	Australia, USA

Abbreviations

IAS: Invasive Alien Species; AAS: Alert Alien Species; IUCN: International Union for Conservation of Nature; IAS Act: Invasive Alien Species Act; UAS: Uncategorized Alien Species; LORCA: Living Organisms Required to Have a Certificate Attached; GBNNSS: Great Britain Invasive Non-Native Species Strategy

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Authors' contributions

SHS and DEK designed the study and wrote the manuscript. SHS and ARJ performed data collect and analyzed the data. The authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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The authors declare that they have no competing interests.

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