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

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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
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 (GBNNSS)” 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 (GBNNSS, 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
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 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 |

**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  |
|Species that have caused social or ecological damage                            | 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 with genetic and ecological characteristics similar to existing IAS     | Promotion of the designation of species that caused social damage such as human diseases and industrial damage |
|Species with a high probability of settlement due to habitat conditions          | Promotion of the designation of species that caused ecological harm through predation, hybridization, etc., of indigenous species |
|Species with a high probability of settlement due to habitat conditions          | Promotion of the IAS designation of similar species expected to have increased demand due to the ballooning effects of IAS designation |
|Species with a high probability of settlement due to habitat conditions          | Promotion of the prioritization of species that are highly likely to spread due to their high fertility rate |
|Species with a high probability of settlement due to habitat conditions          | 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          | Promotion of the prioritization of species that are highly likely to spread due to their high fertility rate |
|Species with a high probability of settlement due to habitat conditions          | Promotion of the prioritization 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
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

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**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.
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.
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.
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.
### Table 4 List of alert alien species in Republic of Korea

| No. | Group  | Scientific name       | Listed in                                      |
|-----|--------|-----------------------|------------------------------------------------|
| 1   | Mammal | *Rattus exulans*      | Australia                                      |
| 2   |        | *Peromyscus maniculatus* |                                               |
| 3   |        | *Callosciurus finlaysonii* | Japan, Europe                                  |
| 4   |        | *Herpestes auropunctatus* | IUCN, Japan                                    |
| 5   |        | *Sciurus aureogaster*  | Japan, USA                                     |
| 6   |        | *Glis glis*           | UK                                             |
| 7   |        | *Castor fiber*        |                                                |
| 8   |        | *Odocoileus virginianus* | New Zealand                                    |
| 9   |        | *Sus scrofa vittatus* | Europe                                         |
| 10  |        | *Lepus californicus*  | USA                                            |
| 11  |        | *Herpestes javanicus* | IUCN, Japan, Europe                            |
| 12  |        | *Sciurus carolinensis* | IUCN, Japan, Europe                            |
| 13  |        | *Mustela erminea*     | IUCN, New Zealand                              |
| 14  |        | *Dasypus novemcinctus* |                                               |
| 15  |        | *Mustela vison*       | Japan, Europe, UK                              |
| 16  |        | *Atelerix albiventris* | Japan                                          |
| 17  |        | *Chlorocebus aethiops* |                                               |
| 18  |        | *Dasypodica leporina* | USA                                            |
| 19  |        | *Desmodus rotundus*   |                                                |
| 20  |        | *Eliomys quercinus*   |                                               |
| 21  |        | *Epomops franqueti*   |                                               |
| 22  |        | *Hypsignathus monstrosus* |                                           |
| 23  |        | *Ovis orientalis*     |                                               |
| 24  |        | *Puma yagouroundi*    | USA                                            |
| 25  |        | *Callosciurus erythroaesus* | Japan, Europe                                |
| 26  | Bird   | *Acridotheres tristis* | IUCN, USA, Australia, New Zealand, Europe       |
| 27  |        | *Passer domesticus*   | Australia, New Zealand, USA                    |
| 28  |        | *Phasianus versicolor* |                                               |
| 29  |        | *Pyconotus jacocus*   | Japan, Australia, USA                          |
| 30  |        | *Streptopelia chinensis* | Australia                                     |
| 31  |        | *Carpodacus mexicanus* | USA                                            |
| 32  |        | *Corvus splendens*    | Europe, UK, Australia, USA                     |
| 33  | Fish   | *Micropterus dolomieu* | Japan                                          |
| 34  |        | *Siniperca chuatsi*   | Japan                                          |
| 35  |        | *Gambusia affinis*    | IUCN, Japan, China, Europe, New Zealand, USA   |
| 36  |        | *Esox lucius*         | Japan                                          |
| 37  |        | *Channa striata*      | USA                                            |
| 38  |        | *Neogobius melanostomus* | Japan, Europe, USA                           |
| 39  |        | *Perca fluviatilis*   | Japan, China, New Zealand, USA                 |
| 40  |        | *Clarias gariepinus*  | China, Europe                                  |
| 41  |        | *Piaractus brachypomus* | China, USA                                     |
| 42  |        | *Pygocentrus nattereri* | China, USA                                     |
| 43  |        | *Atractosteus spatula* | Japan                                          |
| No. | Group | Scientific name          | Listed in                  |
|-----|-------|--------------------------|----------------------------|
| 44  |       | Phractocephalus hemioliopterus |                            |
| 45  |       | Maccullochella peelii    | Japan                      |
| 46  |       | Alosa sapidissima        |                            |
| 47  |       | Alosa pseudoharengus     | USA                        |
| 48  |       | Amia calva               | USA                        |
| 49  |       | Sander lucioperca        | Japan, Europe, USA         |
| 50  |       | Ictiobus cyprinellus     | China                      |
| 51  |       | Ictiobus niger           | Europe                     |
| 52  |       | Labeo rohita             | China                      |
| 53  |       | Lepomis cyanellus        | Japan, USA                 |
| 54  |       | Lepomis megalotis        | Japan                      |
| 55  |       | Micropterus punctulatus  | Japan, USA                 |
| 56  |       | Misgurnus fossilis       |                           |
| 57  |       | Mylopharyngodon piceus   | China                      |
| 58  |       | Paramisgurnus dabryanus  |                           |
| 59  |       | Percottus gleii          | Europe, USA                |
| 60  |       | Petromyzon marinus       |                           |
| 61  |       | Pylocotis olivaris       | Japan, Europe, USA         |
| 62  |       | Salmo salar              | China, Europe              |
| 63  |       | Silurus glanis           | Japan, USA                 |
| 64  |       | Ameiurus nebulosus       | Japan, Europe, New Zealand |
| 65  |       | Ameiurus melas           | Japan, Europe              |
| 66  |       | Morone americana         | Japan, USA                 |
| 67  |       | Morone chrysops          | Japan, USA                 |
| 68  |       | Scardinius erythrophthalmus | New Zealand, USA        |
| 69  |       | Acheilognathus tabira erythrophthalmus | Japan      |
| 70  |       | Aspius aspius            |                           |
| 71  |       | Biwia zezera             |                           |
| 72  |       | Gnathopogon elongatus elongatus |          |
| 73  |       | Ischikauia steenackeri   |                           |
| 74  |       | Ictiobus bubalus         |                           |
| 75  |       | Esox niger               | Japan                      |
| 76  |       | Gasterosteus microcephalus |                          |
| 77  |       | Oncorhynchus masou rhodurus |                        |
| 78  |       | Oncorhynchus clarkii     |                           |
| 79  |       | Catostomus Catostomus    |                           |
| 80  |       | Cobitis biwae           |                           |
| 81  |       | Acheilognathus asmussii  | Japan                      |
| 82  |       | Carassius gibelio        | USA                        |
| 83  |       | Squalius cephalus        |                           |
| 84  |       | Leuciscus leuciscus      |                           |
| 85  |       | Sarcocheilichthys variegatus microaculus |            |
| 86  |       | Lepomis humilis          | Japan, USA                 |
| 87  |       | Channa panaw             |                           |
| No. | Group | Scientific name | Listed in |
|-----|-------|-----------------|-----------|
| 88  |       | Sander volgensis | Japan     |
| 89  |       | Liobagrus reini  |           |
| 90  |       | Lates niloticus  |           |
| 91  |       | Morone saxatilis | Japan, China |
| 92  |       | Gymnocephalus cernua | Japan, USA |
| 93  |       | Leuciscus idus   | New Zealand, USA |
| 94  |       | Alburnus alburnus| USA       |
| 95  |       | Alburnus chalcoides |         |
| 96  |       | Coregonus albula | USA       |
| 97  |       | Coregonus lavaretus| USA       |
| 98  |       | Coregonus maraena| USA       |
| 99  |       | Coregonus peled  | USA       |
| 100 |       | Gambusia holbrooki| Japan, Europe, Australia, USA |
| 101 |       | Ictalurus furcatus| USA, Japan |
| 102 |       | Pterygoplichthys disjunctivus | USA     |
| 103 |       | Pterygoplichthys multiradiatus |         |
| 104 |       | Rutilus rutilus  | USA       |
| 105 |       | Cyprinus carpio var. specularis |       |
| 106 |       | Parachondrostoma toxostoma | Europe |
| 107 |       | Amphilophus citrinellus | USA     |
| 108 |       | Clupeonella tscharchalensis | Europe |
| 109 |       | Cobitis bilineata | Europe    |
| 110 |       | Knipowitschia longicaudata | Europe |
| 111 |       | Neogobius eurycephalus | Japan, Europe |
| 112 |       | Neogobius fluviatilis | Japan, Europe |
| 113 |       | Neogobius gowap   | Japan, Europe |
| 114 |       | Neogobius pallasi  | Japan, Europe |
| 115 |       | Odontesthes bonariensis | USA    |
| 116 |       | Siganus rivulatus  | Europe    |
| 117 | Mollusca | Perna viridis | USA       |
| 118 | Arthropoda | Procambarus fallax | Japan, Europe, USA |
| 119 | Amphibian | Osteopilus septentrionalis | Japan, USA |
| 120 |       | Xenopus laevis    | Europe, UK, USA |
| 121 |       | Rana ridibundus   | Europe, UK |
| 122 |       | Rana lessonae     |           |
| 123 |       | Bufo japonicus formosus | Japan |
| 124 |       | Bufo japonicus japonicus | Japan |
| 125 |       | Fejervarya kawamurai |         |
| 126 |       | Fejervarya sakishimensis |         |
| 127 |       | Rana japonica     |           |
| 128 |       | Pelophylax porosus |           |
| 129 |       | Epidalea calamita  | Japan     |
| 130 |       | Sclerophrys mauritanica |         |
| 131 |       | Rhinella marinus  | IUCN, Japan, Europe, Australia, USA |
Table 4 List of alert alien species in Republic of Korea (Continued)

| No. | Group | Scientific name               | Listed in          |
|-----|-------|-------------------------------|--------------------|
| 132 |       | Pelophylax esculentus         |                    |
| 133 |       | Pelophylax kurtmuehleri       |                    |
| 134 |       | Anaxyrus cognatus             | Japan              |
| 135 |       | Anaxyrus punctatus            | Japan              |
| 136 |       | Cryptobranchus alleganiensis  |                    |
| 137 |       | Duttaphrynus melanostictus    | Japan, USA         |
| 138 |       | Rana grylio                   | Japan, China       |
| 139 |       | Rana heedsleri                | Japan, China       |
| 140 |       | Rana pipiens                  |                    |
| 141 | Reptile | Hylorana erythraea            |                    |
| 142 |       | Hoplobatrachus tigrinus       |                    |
| 143 |       | Hoplobatrachus rugulosus      |                    |
| 144 |       | Litoria dentata               | Australia          |
| 145 |       | Litoria ewingii               | New Zealand        |
| 146 |       | Litoria raniformis            | New Zealand        |
| 147 | Reptile | Boiga irregularis             | IUCN, Japan, Europe, USA |
| 148 |       | Graptemys pseudogeographica   | Europe, USA        |
| 149 |       | Vipera aspis                  |                    |
| 150 |       | Mauremys mutica               | Japan              |
| 151 |       | Graptemys geographica         |                    |
| 152 |       | Mauremys caspica              | Japan              |
| 153 |       | Pelomedusa subrufa             |                    |
| 154 |       | Darevskia armeniaca           |                    |
| 155 |       | Eutropis multifasciata        |                    |
| 156 |       | Calotes mystaceus             | USA                |
| 157 |       | Calotes versicolor            | USA                |
| 158 |       | Protobothrops mucrosquamatus  | Japan              |
| 159 |       | Boiga cyanea                  | Japan              |
| 160 |       | Rhabdophis subminiatus        |                    |
| 161 |       | Boiga cynodon                 | Japan              |
| 162 |       | Boiga nigriceps               | Japan              |
| 163 |       | Notechis scutatus             | Australia          |
| 164 |       | Epicrates maurus              | USA                |
| 165 |       | Ctenotus lancelini            | Australia          |
| 166 |       | Lampropholis delicata         | New Zealand        |
| 167 |       | Mauremys sinensis × Mauremys reevesii | Japan |
| 168 |       | Mauremys japonica × Mauremys reevesii | Japan |
| 169 | Insect | Anoplolepis gracilipes        | IUCN, New Zealand  |
| 170 | Spider | Atrax robustus                | Japan              |
| 171 |       | Latrodectus antheratus        | Japan              |
| 172 |       | Latrodectus apicalis          | Japan              |
| 173 |       | Latrodectus bishopi           | Japan              |
| 174 |       | Latrodectus cinctus           | Japan              |
| 175 |       | Latrodectus corallinus        | Japan              |
| No. | Group | Scientific name              | Listed in                           |
|-----|-------|------------------------------|-------------------------------------|
| 176 |       | *Latrodectus curacaviensis*  | Japan                               |
| 177 |       | *Latrodectus dahli*          | Japan                               |
| 178 |       | *Latrodectus diaquila*       | Japan                               |
| 179 |       | *Latrodectus elegans*        | Japan                               |
| 180 |       | *Latrodectus erythromelas*   | Japan                               |
| 181 |       | *Latrodectus geometricus*    | Japan                               |
| 182 |       | *Latrodectus hasselti*       | Japan                               |
| 183 |       | *Latrodectus hesperus*       | Japan                               |
| 184 |       | *Latrodectus hystrix*        | Japan                               |
| 185 |       | *Latrodectus indistinctus*   | Japan                               |
| 186 |       | *Latrodectus karrooensis*    | Japan                               |
| 187 |       | *Latrodectus katipo*         | Japan                               |
| 188 |       | *Latrodectus lilianae*       | Japan                               |
| 189 |       | *Latrodectus mactans*        | Japan                               |
| 190 |       | *Latrodectus menavodi*       | Japan                               |
| 191 |       | *Latrodectus mirabilis*      | Japan                               |
| 192 |       | *Latrodectus obscurior*      | Japan                               |
| 193 |       | *Latrodectus pallidus*       | Japan                               |
| 194 |       | *Latrodectus quartus*        | Japan                               |
| 195 |       | *Latrodectus renivulvatus*   | Japan                               |
| 196 |       | *Latrodectus revivensis*     | Japan                               |
| 197 |       | *Latrodectus rhodesiensis*   | Japan                               |
| 198 |       | *Latrodectus thoracicus*     | Japan                               |
| 199 |       | *Latrodectus tredecimguttatus* | Japan                          |
| 200 |       | *Latrodectus variegatus*     | Japan                               |
| 201 |       | *Latrodectus*                | Japan                               |
| 202 | Plant | *Vincetoxicum rassicum*      |                                     |
| 203 |       | *Carduus acanthoides*        | USA                                 |
| 204 |       | *Carduus tenuiflorus*        | USA, Australia                       |
| 205 |       | *Chromolaena odorata*        | IUCN, China, Europe, Australia, USA |
| 206 |       | *Mikania micrantha*          | IUCN, Japan, Australia, China, USA  |
| 207 |       | *Senecio madagascariensis*   | Japan, USA, Australia               |
| 208 |       | *Sphagneticola trilobata*    | IUCN, USA, China                    |
| 209 |       | *Cenchrus echinatus*         | China, Australia, USA               |
| 210 |       | *Neyraudia reynaudiana*      | USA                                 |
| 211 |       | *Brachiaria mutica*          | China                               |
| 212 |       | *Vulpia bromoides*           | USA                                 |
| 213 |       | *Fallopia baldschuanica*     | USA, UK                             |
| 214 |       | *Heracleum sosnowskyi*       | Europe                              |
| 215 |       | *Hydrocotyle ranunculoides*  | Japan, Europe, UK, Australia        |
| 216 |       | *Asparagus asparagoides*     | USA, Australia, New Zealand         |
| 217 |       | *Landolphia punctata*        | USA                                 |
| 218 |       | *Elodea nuttallii*           | Europe, UK                          |
| 219 |       | *Andropogon gayanus*         | Australia                           |
| No. | Group | Scientific name | Listed in |
|-----|-------|-----------------|-----------|
| 220 |       | Oenanthe pimpinellioide | Australia |
| 221 |       | Ageratina riparia | USA, Australia, New Zealand |
| 222 |       | Onopordum acanthium | USA |
| 223 |       | Bunias orientalis | Europe, USA |
| 224 |       | Alternanthera pungens | Japan, China, Australia |
| 225 |       | Prosopis glandulosa | IUCN, Europe |
| 226 |       | Salpichroa origanifolia | Australia |
| 227 |       | Myriophyllum heterophyllum | Japan, Europe, USA |
| 228 |       | Salvinia minima | USA |
| 229 |       | Sagittaria graminea | USA, Europe |
| 230 |       | Centaurea diffusa | USA |
| 231 |       | Ehrharta erecta | China, New Zealand, USA |
| 232 |       | Lolium perisicum | China, Canada |
| 233 |       | Paspalum conjugatum | China, USA |
| 234 |       | Hydrocharis morsus-ranae | USA |
| 235 |       | Stratiotes aloides | USA, Australia |
| 236 |       | Eichhornia azurea | USA, Australia |
| 237 |       | Monochoria hastata | USA |
| 238 |       | Aegilops tauschii | China |
| 239 |       | Setaria palmifolia | New Zealand, USA |
| 240 |       | Echinochystis lobata | Europe, USA |
| 241 |       | Lycium ferocissimum | Australia, New Zealand, USA |
| 242 |       | Paspalum fimbriatum | China, USA |
| 243 |       | Berteroa incana | USA |
| 244 |       | Lepidium appelianum | USA |
| 245 |       | Heteropogon contortus | USA |
| 246 |       | Spartina densiflora | Japan, USA |
| 247 |       | Centaurea stoeb subsp. micranthos | Australia, USA |
| 248 |       | Rhipopticum repens | Australia, USA |
| 249 |       | Myriophyllum alterniflorum | Japan, USA |
| 250 |       | Passiflora foetida | China, USA |
| 251 |       | Spartina patens | Japan, USA |
| 252 |       | Acacia paradoxa | Australia, New Zealand, USA |
| 253 |       | Alhagi maurorum | Australia, USA, South Africa |
| 254 |       | Arctotheca calendula | New Zealand, USA |
| 255 |       | Asparagus scandens | Australia, New Zealand |
| 256 |       | Buddleja madagascariensis | New Zealand, USA, South Africa |
| 257 |       | Carpobrotus chilensis | New Zealand, USA |
| 258 |       | Cenchrus spinifex | Australia, USA |
| 259 |       | Crupina vulgaris | Australia, USA, Canada |
| 260 |       | Dolichandra unguis-cati | China, Europe, Australia, South Africa |
| 261 |       | Echium vulgare | USA, Australia, New Zealand |
| 262 |       | Ehrharta longiflora | New Zealand, USA |
| 263 |       | Erica lusitanica | Australia, New Zealand, Pacific islands |
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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Table 4 List of alert alien species in Republic of Korea (Continued)

| No. | Group | Scientific name | Listed in |
|-----|-------|-----------------|-----------|
| 264 |       | Erechtites valerianifolius | China, USA, Pacific islands |
| 265 |       | Euphorbia cyathophora | USA, Pacific islands |
| 266 |       | Flaveria bidentis | China, South Africa |
| 267 |       | Genista linifolia | Australia, USA |
| 268 |       | Genista monspessulana | Australia, USA, Pacific islands, Hawaii |
| 269 |       | Heliotropium europaeum | Australia, China |
| 270 |       | Hordeum bulbosum | China, Australia |
| 271 |       | Hyptis brevipes | China, Australia |
| 272 |       | Hyptis suaveolens | China, Australia, Hawaii, Guam, Papua New Guinea, Philippines, Singapore, Taiwan |
| 273 |       | Ipomoea alba | USA |
| 274 |       | Iva axillaris | Australia, USA |
| 275 |       | Jatropha curcas | China, Australia |
| 276 |       | Lantana montevidensis | China, Australia, New Zealand, USA, Hawaii |
| 277 |       | Megathyrsus maximus | USA |
| 278 |       | Morella faya | Europe, Australia, Hawaii |
| 279 |       | Pittosporum undulatum | Australia, Europe, USA |
| 280 |       | Rosa bracteata | Europe, USA |
| 281 |       | Senecio angulatus | Japan, New Zealand |
| 282 |       | Toxicodendron radicans | Europe, Australia, USA |
| 283 |       | Acacia auriculiformis | USA, Singapore, Hawaii |
| 284 |       | Acacia confusa | China |
| 285 |       | Acacia farnesiana | IUCN, New Zealand, South Africa, Hawaii |
| 286 |       | Acacia meamsii | IUCN, New Zealand, South Africa, Hawaii |
| 287 |       | Agropyron desertorum | |
| 288 |       | Ardisia elliptica | IUCN, Europe, Hawaii |
| 289 |       | Amelanchier spicata | Europe |
| 290 |       | Bassia hyssopifolia | |
| 291 |       | Bromus rubens | |
| 292 |       | Centaurea melitensis | |
| 293 |       | Chrysanthemoides monilifera | New Zealand |
| 294 |       | Cortaderia jubata | Europe, New Zealand, Hawaii, South Africa |
| 295 |       | Cyrtis striatus | |
| 296 |       | Delairea odorata | Australia |
| 297 |       | Dioscorea oppositifolia | |
| 298 |       | Dittrichia graveolens | Australia |
| 299 |       | Galeopsis tetrahit | Alaska |
| 300 |       | Emex spinosa | Australia, USA |
Availability of data and materials
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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