diversity

MDPI

Article

Using Import Data to Predict the Potential of Introduction of Alert Alien Species to South Korea

Aram Jo [1], Seunghun Son [2] and Dongeon Kim [1,*]

[1] Division of Ecological Threat Management, National Institute of Ecology, Seocheon 33657, Korea
[2] Animal Resources Division, National Institute of Biological Resources, Incheon 22689, Korea
* Correspondence: eco0106@nie.re.kr; Tel.: +82-041-950-5803

Abstract: As globalization progresses, human activities, such as travel and trade, are rapidly increasing beyond national boundaries. It is increasingly recognized that places, such as ports and airports, where trade occurs play a major role as an introduction pathway for alien species. In this study, we focused on evaluating the possibility of introduction of Alert Alien Species (AAS) through trade data among countries. The natural and distribution range of AAS were analyzed along with import data by country. There were large differences between the number of AAS distributed in a country and the import weight of items related to the import of AAS from the country. Fish, which account for 76% of the import weight of AAS, 43 and 40 species of the 84 species of AAS were distributed in US and Russia, respectively. However, the import weight of items related to the import of fish designated as AAS from these countries were extremely low. This finding suggests that trade, which is the main introduction pathway, is not taken into account in the designation of AAS. For future management plans for non-introduced alien species, species with a high possibility of introduction into South Korea through trade should be prioritized using import data.

Keywords: invasive alien species; biological invasion; trade; pathway of introduction

Citation: Jo, A.; Son, S.; Kim, D. Using Import Data to Predict the Potential of Introduction of Alert Alien Species to South Korea. *Diversity* **2022**, *14*, 910. https://doi.org/10.3390/d14110910

Academic Editor: Michael Wink

Received: 12 September 2022
Accepted: 24 October 2022
Published: 26 October 2022

1. Introduction

Starting from mass migrations of species during the Middles Ages in the 1500s when Europeans moved to North America to the increased trade in the 1800s during the Industrial Revolution that has continued into the current era of globalization, species' boundaries between countries are gradually disappearing [1]. As a result, this has caused an increase in alien species moving away from their natural range and resulted in damaged ecosystems, hybridization, and competition with native species, which has thereby led to a decline in biodiversity and economic value [2,3]. In South Korea, there has been serious damage caused by invasive alien species such as the spotted lanternfly (*Lycorma delicatula*), nutria (*Myocastor coypus*), and common cordgrass (*Spartina anglica*) [4]. The economic costs of such invasive alien species from 1970 to 2017 have been estimated to be at a minimum of USD 1.28 trillion [5].

According to the 2nd Management Plan of Alien Species (2019–2023) [4], the confirmed number of alien species introduced into South Korea was 1109 species in 2011, which more than doubled to 2160 species in 2018. It is assumed, considering cases of unclear introduction pathway or deliberately unreported import, that many more alien species have been introduced domestically. Accordingly, the Ministry of Environment designated non-introduced alien species with a potential risk of causing harm to the ecosystem if they are introduced in South Korea as "alert alien species (AAS)" to be managed as part of the Act on the Conservation and Use of Biological Diversity (hereafter, the "Biodiversity Act") [2]. The standards for AAS designation are as follows: 1. species whose risks are recognized internationally; 2. species known to have caused social or ecological damage; 3. species which have similar ecological or genetic characteristic to ecosystem-disturbing species

or species with potential risks to the ecosystem; 4. species that have a high possibility of establishment in South Korea because their natural habitat conditions are similar to the environment of South Korea. 5. species known to impact human health or spread various diseases [6]. For AAS, risk assessment must be conducted when they are imported or introduced (Article 22 of the Biodiversity Act). Risk assessment involves evaluating the possibility of introduction, establishment, and spread of the subject species and their impact on ecosystems, society, and the economy (Article 21 (2) of the Biodiversity Act). As of April 2021, 300 species have been designated as AAS [7]. The Ministry of Environment plans to expand the number of AAS to 1000 by [8].

Despite such legal efforts, preventing the introduction and spread of alien species remains highly challenging. Biological invasion, which is the process of species becoming invasive in another habitat away from their original habitat, involves various components such as introduction, establishment, and spread. However, most studies on AAS in South Korea are about the spread and establishment possibility when they are introduced rather than the introduction possibility [9,10].

Alien species are typically introduced into new habitats by human activities such as travel, transport, and trade. Among them, trade is very closely associated with biological invasion [1,11,12]. First, alien species can be introduced unintentionally, such as attached to ships or mixed with other products. *Solenopsis invicta*, designated among 100 of the world's worst invasive alien species by the International Union for Conservation of Nature (IUCN), was found for the first time in the Port of Busan in 2017 and have been found a total of 11 times until 2020 [13]. *Anoplolepis gracilipes* was first found in the wooden packing material of freight entering the Port of Incheon from Vietnam in 2019 [14]. Second, alien species also imported deliberately for various purposes, such as pets and food with the development of transportation, which is considered as the major pathway of alien species in South Korea. Invasive alien species *Rana catesbeiana, Micropterus salmoides*, and *Lepomis macrochirus* were typically introduced for food, but now they are major invasive alien species that causes biodiversity decline. *Mauremys sinensis* and *Macrochelys temminckii* were widely raised as pets, but now they were banned from breeding, transfer, transportation, and importation because they cause great damage in the ecosystem, even though they are an endangered species as CITES [15].

In this study, we focused on evaluating the possibility of introduction of AAS, which is about the 1st step of biological invasion, through trade data among countries. To calculate the possibility of introduction of AAS, their origin and distribution of AAS were analyzed along with import data by country provided by the Korea Customs Service. Through this, implications for the current designation of AAS were proposed.

2. Materials and Methods

2.1. Species Distribution Database

As of April 2021, a total of 300 species have been designated as AAS in 10 taxonomic groups (Notification of the Ministry of Environment, No. 2020-79): mammals, birds, fish, mollusks, amphibians, reptiles, insects, spiders, other arthropods and plants. The data sources for natural and distribution range of each species are as follows: 1. Centre of Agriculture and Biosciences International Invasive Species Compendium (CABI ISC, https://www.cabi.org/isc, accessed on 1 July 2020); 2. Global Invasive Species Database (GISD, http://www.iucngisd.org/gisd/index.php, accessed on 1 August 2020); 3. IUCN Red List (https://www.iucnredlist.org, accessed on 1 August 2020); 4. Catalogue of Life (http://www.catalogueoflife.org, accessed on 1 August 2020); 5. World Spider Catalog (https://wsc.nmbe.ch, accessed on 1 September 2020); and 6. Other data sources of reported regions invaded by alien species identified by an Internet search.

Based on import and export trade statistics from the Korea Customs Service (https://unipass.customs.go.kr/ets/index.do, accessed on 1 April 2021), trading countries were classified into eight regions: Asia, Middle East, Europe, North America, Latin America, Africa, Oceania, and Islands of Oceania. The total number of trading countries included

was 255, including 32 countries in Asia, 21 countries in Middle East, 58 countries in Europe, 2 countries in North America, 54 countries in Latin America, 56 countries in Africa, 18 countries in Oceania, and 14 countries in Islands of Oceania. When a species is distributed across a continent, it indicates that the species is distributed in a certain country belonging to the continent, not the entire continent.

2.2. Import Data

The Korea Customs Service provides data on the number of imports and weight imported from a port or airport. The import data required for analysis were collected through the following three ways for each trading country:

In order to compare the possibility of introduction of alien species including AAS through import itself, data on the number of imports for all import items for the 5 years from 2016 to 2020 were obtained. In addition, the number of imports for the 20 years from November 2001 to November 2020 was used to compare long-term changes in the number of imports by continent.

Data on the import weight related to living organisms were organized to evaluate the possibility of alien species directly imported or unintentionally mixed with other living organisms. The number of imports by item type was not recorded in the statistics; thus, the overall weight of import was used. First, import items related to living organisms were selected from "property classification" of the Korean Customs Service (Table 1). Then, import weight not related to living organisms in each item such as byproducts of processed items. However, the weight of Shellfish and Squids was recorded by a combination of live and refrigerated. The weight of imported items from trading countries from 2016 to 2020 was aggregated by continent. Because no items related to living organisms were imported from Island of Oceania, this region was excluded from the statistical evaluation by continent.

Table 1. Items used for the possibility of introduction by import of living organisms among "property classification" of the Korean Customs Service.

Main Category	Subcategory		Item	Classification
Consumer goods	Direct consumption goods	Agricultural products	All items except for products, by-products, and processed goods	Plants
		Animal products	Live animals	Animals
		Marine products	Fish (live fish)	
			Crustaceans (not smoked)	
			Shellfish (live, fresh, refrigerated)	
			Squids (live, fresh, refrigerated)	
			Seaweeds	
			Other marine products	
Raw materials	Fuel/raw materials of animals and plants	Agricultural products	Live part of trees	Plants
			Tree seeds	
			Flowering plants	
			Vegetables and their seeds	
			Feedstuff	

The weight of imported AAS was organized based on the 23 Harmonized System (HS) codes (Table 2). The Ministry of Environment designated 23 HS codes which are

highly likely to be related to the import of AAS. Though the weight was not suitable for comparison between animals and plants or between species, the number of import cases by HS codes were not recorded in the Korean Custom Service. The 23 HS codes were classified as mammals, reptiles, birds, insects, amphibians, fish, other arthropods, mollusks, other animals, and plants based on the properties of the items. Among the 23 HS codes, "animal products (0410009000)" were excluded because they are not imported alive. "Other living organisms (0106909000)" were classified as "other animals" because there were several animal taxa in that code. Spiders of AAS were not included among the 23 HS codes. The weight of imported items by country from 2016 to 2020 was obtained for each item and aggregated by continent.

Table 2. Items subject to 23 HS Code related to AAS. No. 20, animal products were excluded from statistics because they were not imported alive.

No.	HS CODE	Item	Classification
1	0103920000	Living organisms weighing 50 kg or more, such as pigs	Mammals
2	0106149000	Other species such as rabbits	Mammals
3	0106193000	Deer	Mammals
4	0106196090	Other species such as mink	Mammals
5	0106199000	Other mammals	Mammals
6	0106201000	Snakes	Reptiles
7	0106203000	Turtles	Reptiles
8	0106209000	Other reptiles	Reptiles
9	0106390000	Other birds	Birds
10	0106490000	Other insects	Insects
11	0106901000	Amphibians	Amphibians
12	0106909000	Other living organisms	Other animals
13	0301119000	Live ornamental fish	Fish
14	0301911000	*Salmo trutta*, etc.	Fish
15	0301930000	Carp	Fish
16	0301999070	Mudfish	Fish
17	0301999080	Catfish	Fish
18	0306390000	Crustaceans	Other arthropods
19	0307310000	Living organisms such as mussels, etc.	Mollusks
20	0410009000	Animal products	-
21	0602909090	Plants	Plants
22	1209300000	Flower seeds	Plants
23	1209999000	Sowing seeds	Plants

2.3. Calculation of the Possibility of Introduction

To calculate the possibility of introduction (P_i), the number of AAS distributed in one country (S_i) was multiplied by the number of import or weight (V_i) from that country to South Korea. The number of AAS (S_i) and the number of import or weight (V_i) were divided by the largest value and ranged from 0 to 1, respectively.

$$P_i = S_i \times V_i$$

$$(S_1 = S_2 = S_5)$$

The possibility of introduction was calculated on the premise that the more AAS distributed in the country, or the more items and weight imported, the higher the possibility of introduction [9,12,16–18]. The possibilities of introduction from each country were aggregated for comparison by continent. A total of five possibilities of introduction (P_i) were calculated according to the taxanomic groups of AAS and types of import items (Table 3): P_1 simply represent the possibility of introduction from both the number of AAS in a country and the number of imports from the country based on the premise. P_2 indicates the possibility of AAS being deliberately introduced alive or introduced though a mixture with other living organisms. P_3 and P_4 indicate the possibilities of introduction of AAS as items related to animal and marine species alive, respectively. Finally, P_5 indicates the possibility of AAS being introduced via items included in the 23 HS codes.

Table 3. Description of variables related to the possibility of introduction.

i	P_i	S_i	V_i
1	Possibility of introduction by import	No. of AAS in one country	No. of import
2	Possibility of introduction by import of living organisms	No. of AAS in one country	Weight of imported living organisms (ton)
3	Possibility of introduction by import of animal products	No. of animals except fish among AAS in one country	Weight of imported animal species (ton)
4	Possibility of introduction by import of marine products	No. of fish among AAS in one country	Weight of imported marine species (ton)
5	Possibility of introduction by import of 23 HS codes	No. of AAS in one country	Weight of 23 HS codes-related imported AAS (kg)

3. Results

3.1. Distribution of AAS

The results of investigating the natural range of AAS by continent showed that 213 of the 300 species had one continent as the natural range and the other 87 species had at least two continents. The number of species with a natural range in Asia was the highest with 106 species, followed by 85 species from Europe, 68 species from North America, 63 species from Latin America, 45 species from Africa, 29 species from Middle East, 23 species from Oceania, and no species from Islands of Oceania (Figure 1A). In terms of distribution, 69 species were distributed in a single continent, whereas the others were distributed throughout various continents. The majority of AAS were distributed in Asia with 199 species, followed by North America with 181 species, Europe with 172 species, Latin America with 150 species, Oceania with 117 species, Middle East with 113 species, Africa with 102 species, and Islands of Oceania with 41 species (Figure 1B).

When compared by taxa, the amphibians and reptiles designated AAS were mainly distributed in Asia. Similarly, fish mainly distributed in Asia and Europe were designated as AAS (Figure 1B). In the case of plants designated as AAS, when the natural range and distribution range were compared, the number was very large, so it was clearly seen that they were distributed as alien species in most continents. In particular, in the case of Islands of Oceania, all taxa designated as AAS were found to be invasive species. Of the 300 species of AAS, 17 species (1 species of birds, 2 species of fish, and 14 species of plants) were distributed in all eight continents.

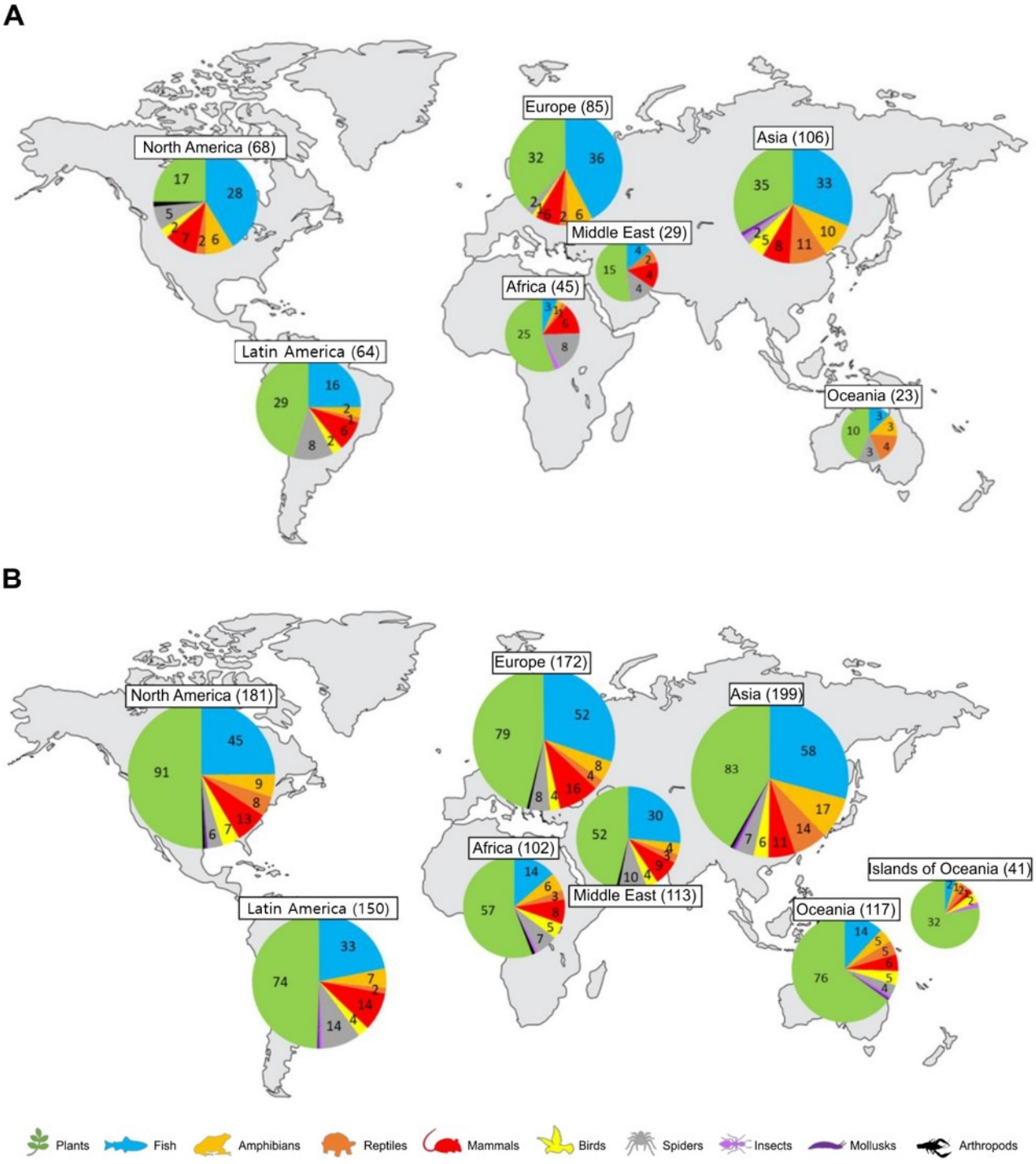

Figure 1. Number of alert alien species according to the natural range and distribution range (both natural range and alien range) by continent. (**A**) Natural range. (**B**) Distribution range.

Regarding the number of AAS distributed by country, the United States predominated with 179 out of 300 species (Table 4, Table S1), followed by China with 110 species, Australia with 101 species, France with 96 species, and Spain with 94 species. Fish were distributed mostly in the United States (43 species) and Russia (40 species) in comparison with other countries (<30 species). In the case of plants, 90 out of 99 species were distributed in the United States, followed by Australia with 71 species.

Table 4. The top 10 countries with large numbers of AAS distributed by taxonomic groups. Taxonomic groups with small numbers of species were excluded (birds, mollusks, insects and other arthropods). See Table S1 for the entire country rankings and the numbers of AAS distributed by countries in all taxonomic groups.

	Mammals (25)	**Reptiles (22)**	**Amphibians (28)**	**Fish (84)**	**Spiders (32)**	**Plants (99)**
1	USA (13)	China (9)	USA (9)	USA (43)	USA (7)	USA (90)
2	Mexico (10)	USA (8)	Japan (9)	Russia (40)	Argentina (6)	Australia (71)
3	Belgium (8)	Vietnam (8)	China (7)	Rumania (28)	South Africa (4)	Spain (57)
4	Italia (8)	Thailand (8)	Spain (6)	Canada (28)	Madagascar (4)	China (54)
5	The Czech Republic (8)	Myanmar (7)	UK (6)	Germany (27)	Israel (4)	India (50)
6	Croatia (8)	Bangladeshi (7)	France (6)	Bulgaria (27)	India (4)	France (50)
7	France (8)	India (7)	Taiwan (5)	France (26)	Canada (4)	Mexico (47)
8	Belarus (7)	Indonesia (7)	Denmark (5)	Ukraine (25)	Australia (4)	Argentina (43)
9	Slovakia (7)	Laos (6)	Germany (5)	China (25)	Russia (3)	Italia (42)
10	Austria (7)	Malaysia (6)	Mexico (5)	Kazakhstan (25)	United Arab Emirates (3)	New Zealand (41)

3.2. Import Data

Asia recorded the largest number of imports, with 1,830,779 cases in 2001 increasing to 4,311,247 cases in 2010 and to 7,593,158 cases in 2020, indicating a 2.35-fold and 4-fold increase, respectively (Figure 2). North America recorded 1,000,000 cases in 2008 and 16,153,841 in 2020, showing the fastest growth rate. As of 2020, North America, Asia, Europe, and Oceania exceeded 1,000,000 cases of import. Among them, the United States had the most cases with 15,901,241 cases in a single year (2020), followed by China with 4,565,009 cases, Germany with 2,669,119 cases, and Japan with 1,864,174 cases (Table S1).

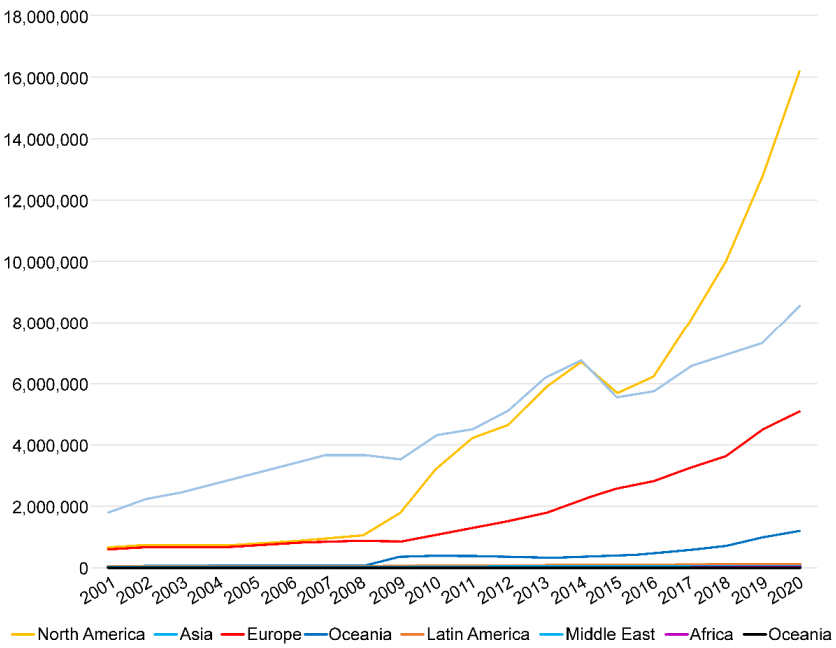

Figure 2. The total number of imports by continent.

Among the 255 trading countries, 157 countries were engaged in trade related to living organisms (Table 5). The weight of imported living organisms over the last 5 years

totaled 154,782,190 tons from seven continents (excluding Islands of Oceania), of which 99.8% accounted for agricultural products. Approximately 41% of the total weight of imported agricultural products was from North America, followed by Latin America with approximately 20%. The largest import volume by country was, in order, the US, Brazil, Australia, China, and Argentina (Table 6). The amount of agricultural products imported from Asia was the largest at 43.5%, followed by North America at 28%. Marine products were also imported mostly from Asia at 57.5%, followed by Europe at 25.2%.

Table 5. The weight (in tons) of imported living organisms by continent.

	The Total Number of Trading Countries	The Number of Relevant Countries	Total Weight	Agricultural Products	Animal Products	Marine Products
Asia	32	27	22,132,038 (14.30%)	21,932,304 (14.20%)	3265 (43.50%)	196,469 (57.52%)
North America	2	2	63,442,312 (40.99%)	63,427,137 (41.07%)	2106 (28.06%)	13,069 (3.83%)
Latin America	54	29	30,823,371 (19.91%)	30,804,156 (19.95%)	189 (2.52%)	19,027 (5.57%)
Europe	58	40	21,664,536 (14.00%)	21,576,766 (13.97%)	1798 (23.96%)	86,001 (25.18%)
Oceania	14	7	15,077,894 (9.74%)	15,077,620 (9.76%)	136 (1.81%)	139 (0.04%)
Africa	56	36	1,572,800 (1.02%)	1,569,256 (1.02%)	10 (0.13%)	3,543 (1.04%)
Middle East	21	16	69,239 (0.04%)	45,921 (0.03%)	2 (0.03%)	23,316 (6.83%)
Islands of Oceania	18	-	-	-	-	-
Total	255	157	154,782,190 (100%)	154,433,158 (100%)	7506 (100%)	341,564 (100%)

Table 6. The order of continents with the large weight of imported living organisms.

Order	Total Sum		Agricultural Products			Animal Products			Marine Products		
	Country	Weight (ton)	Order	Country	Weight (ton)	Order	Country	Weight (ton)	Order	Country	Weight (ton)
1	USA	60,331,124	1	USA	60,316,747	1	China	2896	1	Vietnam	171,554
2	Brazil	16,629,299	2	Brazil	16,629,275	2	USA	1308	2	Russian Federation	80,531
3	Australia	14,522,032	3	Australia	14,521,950	3	Netherlands	1036	3	Malaysia	19,745
4	China	11,804,020	4	China	11,801,124	4	Canada	798	4	Bahrain	13,168
5	Argentina	10,263,207	5	Argentina	10,253,066	5	Denmark	191	5	USA	13,069
6	Ukraine	7,574,825	6	Ukraine	7,574,824	6	France	188	6	Argentina	10,132
7	Russian Federation	6,873,080	7	Russian Federation	6,792,538	7	Bahamas	178	7	Mexico	7826
8	Philippines	3,780,228	8	Philippines	3,780,225	8	Germany	169	8	Saudi Arabia	6166
9	Vietnam	3,352,726	9	Serbia	3,225,854	9	Japan	168	9	Norway	4373
10	Serbia	3,225,855	10	Vietnam	3,181,165	10	Indonesia	130	10	Morocco	3970
11	Canada	3,111,188	11	Canada	3,110,391	11	Australia	82	11	Myanmar	3629
12	Paraguay	1,883,921	12	Paraguay	1,883,921	12	Spain	55	12	Namibia	2709
13	Thailand	1,875,191	13	Thailand	1,875,142	13	New Zealand	53	13	Taiwan	821

According to the import weight data arranged by the 23 HS codes, a total of 70,412,084 kg was imported over the last 5 years from seven continents, and the weight of imported living organisms (154,782,227 tons) was extremely small at 0.05% (Table 7). Asia accounted for the largest weight at 94.32%. According to the taxonomic groups, fish comprised 76.66% of the entire weight of import, and plants comprised 22.11%, indicating that both groups accounted for 98.77% of all import weight.

In terms of the imported AAS by taxonomic group, China had the largest import weight of mammals, reptiles, amphibians, fish, and plants, accounting for 90.86% overall (Table 8). Mammals were mostly imported from Japan, China, and Denmark. Reptiles were mostly imported from the US, China, and Nicaragua, whereas birds and insects were mostly imported from the Netherlands. For amphibians, China predominated at 97%, followed by the US and Indonesia. China also predominated for fish at 63.7%, followed by the US, Indonesia, and Costa Rica. For other animals, the Netherlands was the largest importing country accounting for 74.2% of weight.

Table 7. The order of continents with the large import weight (kg) of 23 HS codes by taxonomic groups of AAS.

	Continent	Total Weight	Mammals	Reptiles	Birds	Insects	Amphibians	Fish	OtherArthropods	Mollusks	Plants	Other Animals	
1	Asia	66,415,365 (94.324%)	226,281 (0.34%)	39,823 (0.06%)	110 (0.00%)	41 (0.00%)	99,430 (0.15%)	53,957,360 (81.24%)	3345 (0.01%)		12,088,971 (18.20%)	4 (0.00%)	(100%)
2	North America	1,624,946 (2.308%)	41,564 (2.56%)	6256 (0.38%)	98 (0.01%)	593 (0.04%)	1108 (0.07%)	215 (0.01%)		31 (0.00%)	1,574,990 (96.93%)	91 (0.00%)	(100%)
3	Europe	952,508 (1.353%)	38,966 (4.09%)	4257 (0.45%)	1633 (0.17%)	144,931 (15.22%)	297 (0.03%)	3973 (0.42%)	1 (0.00%)	174,118 (18.28%)	519,691 (54.56%)	64,641 (6.79%)	(100%)
4	Africa	9890 (0.014%)	715 (7.23%)	5164 (52.21%)	22 (0.22%)		278 (2.81%)	941 (9.51%)			2756 (27.87%)	14 (0.14%)	(100%)
5	Oceania	9908 (0.014%)	1755 (17.71%)	14 (0.14%)		13 (0.13%)		137 (1.38%)	171 (1.73%)	7445 (75.14%)	368 (3.71%)	5 (0.05%)	(100%)
6	Lain America	1,397,362 (1.985%)	576 (0.04%)	581 (0.04%)	20 (0.00%)		28 (0.00%)	15,900 (1.14%)			1,380,257 (98.78%)		(100%)
7	Middle East	2105 (0.003%)	504 (23.94%)	1416 (67.27%)		3 (0.14%)	19 (0.90%)	120 (5.70%)			36 (1.71%)	7 (0.33%)	(100%)
	Total	70,412,084 (100%)	310,361 (0.44%)	57,511 (0.08%)	1883 (0.00%)	145,581 (0.21%)	101,160 (0.14%)	53,978,646 (79.66%)	3517 (0.00%)	181,594 (0.26%)	15,567,069 (22.11%)	64,762 (0.09%)	

Table 8. The order of countries with the large weight (Kg) of 23 HS codes by taxonomic groups of AAS.

	Mammals	**Reptiles**	**Birds**	**Insects**	**Amphibians**	**Fish**	**OtherArthropods**	**Mollusks**	**Plants**	**Other Animals**
1	Japan (149,950)	USA (32,343)	Netherlands (946)	Netherlands (134,029)	China (98,138)	China (53,838,992)	Indonesia (1990)	Russia (174,118)	China (9,930,594)	Netherlands (48,062)
2	China (73,420)	China (5352)	Spain (320)	Belgium (6700)	USA (947)	Indonesia (52,792)	Thailand (469)	New Zealand (7445)	USA (1,558,018)	Belgium (8619)
3	Denmark (23,780)	Nicaragua (3702)	Germany (210)	Spain (3826)	Indonesia (691)	Sri Lanka (30,069)	China (351)	Canada (31)	Indonesia (1,553,410)	Spain (7701)
4	USA (21,717)	Peru (2856)	Czech (100)	USA (560)	Hong Kong (208)	Singapore (25,050)	Singapore (282)		Costa Rica (1,329,013)	Germany (250)
5	Canada (19,847)	Venezuela (1977)	USA (88)	Austria (171)	Togo (206)	Columbia (10,149)	Taiwan (252)		Netherlands (415,894)	USA (90)
6	Netherlands (5118)	Syria (1912)	Philippines (58)	Turkey (130)	Netherlands (161)	Taiwan (6633)	Australia (171)		Thailand (288,593)	UK (9)
7	Germany (2343)	Ghana (1909)	Japan (52)	Switzerland (39)	Canada (161)	Peru (5656)	Germany (1)		Philippines (109,801)	Togo (8)
8	France (2103)	Mauritius (904)	Portugal (40)	Canada (33)	Taiwan (120)	Japan (2662)	Sri Lanka (1)		Taiwan (73,855)	Egypt (7)
9	Russia (1860)	Jordan (634)	Tanzania (22)	Germany (25)	Japan (103)	Germany (2428)			Guatemala (43,811)	Australia (5)
10	Australia (1662)	Belize (557)	Argentina (20)	Japan (22)	Singapore (100)	Czech (1393)			Denmark (39,513)	Ghana (2)
	Other countries (8561)	Other countries (5365)	Other countries (27)	Other countries (46)	Other countries (325)	OtherCountries (2822)			Other countries (244,567)	Other countries (9)
Total	310,361	57,511	1883	145,581	101,160	53,978,646	3517	181,594	15,567,069	64,762

3.3. The Possibility of Introduction

The results of comparing the possibility of introduction by import (P_1) by country showed that the US (1.000) had the highest value compared to other countries, followed by China (0.212), Germany (0.075), Japan (0.070), and Italy (0.025) (Table 9). Comparing P_1 by continent, North America (1.0060) had the highest value, followed by Asia (0.3269) and Europe (0.1435) (Table 10). The results of comparing the possibility of introduction by import of living organisms (P_2), instead of total number of imports, showed the US (1.000) to have the highest value, followed by Australia (0.136), China (0.120), Brazil (0.086), and Argentina (0.060). Comparing P_2 by continent, North America (1.0213) had the highest value like that in P_1, followed by Asia (0.1689) and Latin America (0.1593). Excluding agricultural products, which accounts for 99.8% of the import of living organisms, the results of the possibility of introduction by import of animal species (P_3) showed that China (0.705) had the highest value, followed by the US (0.452), Canada (0.106), Netherlands (0.090), and Japan (0.037). Regarding marine species (P_4), Russia (0.417) had the highest value, followed by Vietnam (0.200), the US (0.076), Malaysia (0.026), and Mexico (0.024). Lastly, calculating the possibility of introduction by import of 23 HS codes (P_5) revealed the highest value for China (0.615), followed by the US (0.025), Indonesia (0.007), Costa Rica (0.005), and Netherlands (0.003); the results by continent were Asia (0.6256), North America (0.0251), and Europe (0.0052).

Table 9. The order of countries and continents with the high possibility of introduction of AAS.

Country Order	P_1	P_2	P_3	P_4	P_5
1	USA (1.000)	USA (1.000)	China (0.704)	Russia (0.417)	China (0.615)
2	China (0.212)	Australia (0.136)	USA (0.452)	Vietnam (0.200)	USA (0.025)
3	Germany (0.075)	China (0.120)	Canada (0.106)	USA (0.076)	Indonesia (0.007)
4	Japan (0.070)	Brazil (0.086)	Netherlands (0.090)	Malaysia (0.026)	Costa Rika (0.005)
5	Italy (0.025)	Argentina (0.090)	Japan (0.037)	Mexico (0.024)	Netherlands (0.003)
6	Australia (0.023)	Russia (0.052)	France (0.028)	Norway (0.010)	Thailand (0.001)
7	UK (0.013)	Ukraine (0.043)	Indonesia (0.021)	Argentina (0.008)	Russia (0.001)
8	New Zealand (0.012)	Canada (0.021)	Germany (0.019)	Morocco (0.006)	Japan (0.001)
9	France (0.011)	Vietnam (0.016)	Denmark (0.018)	Myanmar (0.003)	Philippines (0.0004)
10	Vietnam (0.011)	Philippines (0.016)	Australia (0.014)	Saudi Arabia (0.002)	Taiwan (0.0003)

Table 10. The order of continents with the high possibility of introduction of AAS.

Continent Order	P_1	P_2	P_3	P_4	P_5
1	North America (1.0060)	North America (1.0213)	Asia (0.7736)	Europe (0.4298)	Asia (0.6256)
2	Asia (0.3269)	Asia (0.1689)	North America (0.5582)	Asia (0.2301)	North America (0.0251)
3	Europe (0.1435)	Latin America (0.1593)	Europe (0.1784)	North America (0.0762)	Europe (0.0052)
4	Oceania (0.0354)	Oceania (0.1388)	Oceania (0.0196)	Latin America (0.0327)	Latin America (0.0051)
5	Latin America (0.0059)	Europe (0.1318)	Latin America (0.0081)	Middle East (0.0081)	Oceania (0.0001)
6	Middle East (0.0009)	Africa (0.0072)	Africa (0.0003)	Africa (0.0006)	Africa (0.00003)
7	Africa (0.0005)	Middle East (0.0002)	Middle East (0.0001)	Oceania (0.0001)	Middle East (0.000005)

4. Discussion

According to our analysis of the natural range and the distribution of AAS, the largest number of species was native to Asia. The results indicated that Asia was the natural range of 106 species and the distribution of 199 out of the 300 species. In contrast, in the comparison by country, the AAS were distributed in the US, China, Australia, France, and

Spain in order. Notably, 90 out of 99 plant species designated as AAS were distributed in the US. Plants had the widest geographical distribution because they are more convenient to store and transport compared with animals, which have many constraints for live transport, and have a longer duration of survival.

However, the possibility of introduction considered together with distribution and import data showed different results from the distribution alone. First, the possibility of introduction by import (P_1), calculated together with the number of import and the distribution data, was equivalent to the countries with the largest number of imports in the order of the US, China, Germany, Japan, and Italy. As in the case of Spain and France, if there were a low number of imports, despite the AAS being distributed more than in other countries, the possibility of introduction was much lower. Several studies have investigated the relationship between the introduction of alien species and trade. Liebhold et al. [19] used invasion history records to show that the freight of passengers entering the US was an important introduction channel for alien insects. Moreover, their results showed that the number of alien insects whose introduction blocked was relative to the volume of air transportation entering the country. Tatem et al. [20] found that the volume of marine transportation and climate played major roles in the dispersal of the Asian tiger mosquito (*Aedes albopictus*), which spreads dengue. Westphal et al. [12] conducted regression tree analyses of the distribution of alien species belonging to the GISD using a total of 26 variables and found that the degree of international trade was the most accurate variable predicting the number of alien species in one country.

Even though P_1 corresponds to the entire possibility of introduction through various routes, including unintentional introduction by trade itself, biological invasion is closely related to directly importing live alien species [17,21]. In South Korea, there have been many past cases of unintentional results of such imports, including the spread of infectious diseases, introduction of plant diseases and insect pests, and threatened ecosystems [22]. In this study, the possibility of introduction by import of living organisms (P_2) was different from P_1 calculated using the total number of import cases. Although Germany, Japan, and Italy had a large number of imports in P_1, they showed a low possibility of introduction related to living organisms. P_2 was high for the US, Australia, China, Brazil, and Argentina in that order. Furthermore, the low value in Brazil is due to the small number of distributed AAS despite the high weight of imports. When animal species were calculated separately from living organisms, the possibility of introduction of animal species (P_3) was high for the US, Canada, Netherlands, and Japan. When marine species were calculated separately from living organisms, Russia, Vietnam, the US, Malaysia, and Mexico had a high possibility of introduction (P_4) value. The results of calculating countries with a high possibility of introduction according to certain imported items showed different results. Thus, several studies have specifically compared the import volume of related items to investigate the possibility of introduction of particular taxonomic groups. Chapman et al. [17] found that when countries belonging to the Europe and Mediterranean Plant Protection Organization increased the volume of imports of agricultural products, invasive plant pests (invertebrates, pathogens, and plants) also increased. Similarly, Bradie et al. [23] predicted invasive alien fish with high possibility of settlement using import records of live fish and data on ornamental fish.

More specifically, the import weight of items that are highly likely to be related to import of AAS was inferred from the weight of imported items corresponding to the 23 HS codes. In the comparison by continent, Asia accounted for 94.32% of overall import weight. However, in the comparison by country, Indonesia, Costa Rica, Netherlands, and Thailand, where few AAS are distributed, had a large import weight of AAS, thus indicating a high possibility of introduction (P_5). For the taxonomic groups, there were large differences between the number of AAS distributed in a country and the import weight of items related to the import AAS from the country.

Since the possibility of introduction of alien species is higher in countries with a large number of import cases or import weight, it is appropriate to preferentially manage

invasive alien species distributed in that countries as AAS. However, when looking at the relationship between the distribution of AAS and the trade, it seems that these points were not taken into account when designating AAS. In the case of Fish, which account for 76% of the import weight of AAS, 43 and 40 species of the 84 species of AAS were distributed in US and Russia, respectively. However, the import weight of items related to import of fish designated in AAS from these countries were extremely low. Although 99.7% of these items were imported from China, only 25 species were distributed in the United States, but the import weight related to the import of plants designated as AAS accounts for only 10% of the total. Although Australia and Spain showed extremely low import weight of plants, 71 and 57 of the alert alien plant species, respectively, were distributed in these counties, which is higher than other countries.

These predictive results may be influenced by the diversity and accuracy of variables included in the calculation. In order for alien species to successfully invade a new habitat, the propagule pressure, understood as a composite measure of the number of individuals released into a region in which they are not native, is important, which is estimated using the import weight and the number of imports in this study [10,23,24]. The increased cases and import weight can overwhelm the impact of species characteristics on biological invasion because they reduce the effect of genetic bottlenecks and increase the chances of genetic variation that are favorable in the invaded places [25,26]. In this study, which deals with several taxa, the possibility of introduction of AAS was calculated using only the import weight and distribution of AAS because it is difficult to reflect the characteristics of each taxonomic group with respect to biological invasion. However, according to the "tens rule," which states that only 10% of introduced alien species become invasive through establishment and dispersal, habitat suitability cannot be disregarded [27]. In order to effectively manage alien species with limited cost, it is very important to prioritize among the introduced alien species. As a result of analyzing the two main stages of biological invasion, introduction and establishment, across the world, habitat suitability must be reflected in information on introduction pathways in order to identify the area or species that should be managed first [28,29]. In a study by Chapman et al. [17] of various models predicting the possibility of biological invasion, the most accurate model considered both climate similarity and trade volume. Thus, future research assessing the possibility of introduction of AAS should consider the species-specific life cycle of each AAS and properties of habitats, including climate along with the possibility of introduction by import.

5. Conclusions

As globalization progresses, human activities, such as travel and trade, are rapidly increasing beyond national boundaries. It is increasingly recognized that places, such as ports and airports, where trade occurs play a major role as introduction pathways for alien species. Owing to such human activities, the number of alien species are increasing worldwide [30,31]. Accordingly, South Korea has started to manage alien species through the designation of AAS which may harm ecosystems if introduced into South Korea. As of April 2021, 300 species have been designated as AAS from 10 taxonomic groups, including mammals, birds, fish, mollusks, amphibians, reptiles, insects, spiders, other arthropods and plants [7].

In this study, the natural range and distribution of AAS were analyzed along with import data by countries to calculate the possibility of introduction of AAS. In the process of designation of AAS to prevent introduction of invasive alien species, it seems that the close relationship between trade and introduction of alien species was not fully considered. For future management plans for non-introduced alien species, species with high possibility of introduction into South Korea through trade should be prioritized using import data. It is also necessary to study hitchhikers, which were known to move through trade and were considered a major introduction route for alien species, but were not included in the trade data. Moreover, in order to prevent the introduction of AAS and calculate more accurate

possibility, a more efficient quarantine system than the current 23 HS codes is needed. To that end, it is essential that related authorities work collaboratively, including the Ministry of Environment, Korea Customs Service, and Animal and Plant Quarantine Agency.

There are many papers dealing with introduction risks of alien species. However, most studied focused on the current status, spread and establishment of alien species already-established rather than how alien species will be introduced [16,32,33]. There is few research comparing the possibility of introduction of AAS that should be prevented with top priority among non-introduced alien species in South Korea. Unlike other studies comparing overall trade volume and the number of trade cases, the import items related to living organisms was selected and the possibility of introduction was compared in detail in this study. This approach is meaningful in determining the priority for the management and prevention of invasive alien species by obtaining predictive values of the introduction, which is the first step of biological invasion. We hope that this study can serve as a stepping stone for more accurately predicting the possibility of introduction of AAS in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/d14110910/s1, Table S1: Total data of number of AAS and number of import /weight of each country.

Author Contributions: Conceptualization, A.J. and D.K.; data curation, A.J. and S.S.; formal analysis, A.J. and S.S.; funding acquisition, D.K.; investigation, A.J. and S.S.; methodology, A.J.; project administration, D.K.; supervision, D.K.; visualization, A.J.; writing—original draft, A.J.; writing—review and editing, A.J. and D.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Institute of Ecology (NIE), funded by the Ministry of Environment (MOE) of the Republic of Korea (NIE-A-2022-08 and NIE-D-2022-09).

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Hulme, P.E. Trade, transport and trouble: Managing invasive species pathways in an era of globalization. *J. Appl. Ecol.* **2009**, *46*, 10–18. [CrossRef]
2. Kim, D.E. Management System of Invasive Alien Species Threating Biodiversity in Korea and Suggestions for the Improvement. *J. Environ. Impact Assess.* **2018**, *27*, 33–55.
3. Park, Y.H.; Kim, J.W.; Jung, H.C. Climate change and ecosystem based management strategies of invasive alien species. *Repub. Korea Korea Environ. Inst.* **2015**. [CrossRef]
4. Ministry of Environment. *Establishment of the 2st Management Plan of Alien Species (2019–2023)*; Ministry of Environment: Seocheon, Korea, 2019.
5. Diagne, C.; Leroy, B.; Vaissière, A.C.; Gozlan, R.E.; Roiz, D.; Jarić, I.; Salles, J.M.; Bradshaw, C.J.; Courchamp, F. High and rising economic costs of biological invasions worldwide. *Nature* **2021**, *592*, 571–576. [CrossRef] [PubMed]
6. *100 Alert Alien Species in Korea (II)*; Ministry of Environment: Seocheon, Korea, 2021.
7. Son, S.H.; Jo, A.R.; Kim, D.E. Current status of alert alien species management for the establishment of proactive management systems in Korea. *J. Ecol. Environ.* **2021**, *45*, 26.
8. Ministry of Environment. *Additional Designation of 102 Alert Alien Species*; Ministry of Environment: Seocheon, Korea, 2021.
9. Chapman, D.S.; Makra, L.; Albertini, R.; Bonini, M.; Páldy, A.; Rodinkova, V.; Šikoparija, B.; Weryszko-Chmielewska, E.; Bullock, J.M. Modelling the introduction and spread of non-native species: International trade and climate change drive ragweed invasion. *Glob. Change Biol.* **2016**, *22*, 3067–3079. [CrossRef]
10. Tatem, A.J.; Hay, S.I. Climatic similarity and biological exchange in the worldwide airline transportation network. *Proc. R. Soc. B Biol. Sci.* **2007**, *274*, 1489–1496. [CrossRef]
11. Drake, J.M.; Lodge, D.M. Global hot spots of biological invasions: Evaluating options for ballast–water management. *Proc. R. Soc. Lond. Ser. B Biol. Sci.* **2004**, *271*, 575–580. [CrossRef]
12. Westphal, M.I.; Browne, M.; MacKinnon, K.; Noble, I. The link between international trade and the global distribution of invasive alien species. *Biol. Invasions* **2008**, *10*, 391–398. [CrossRef]

13. Kim, D.E.; Lee, H.; Ban, Y.-G.; Jo, A.; Park, J.; Kim, M.J. *Ecology and Management Manual of Solenopsis invicta in Korea*; Ministry of Environment: Seocheon, Korea, 2020.
14. Ministry of Environment. *Anoplolepis Gracilipes Found in Import Cargo. Pest Control Conducted*; Ministry of Environment: Seocheon, Korea, 2019.
15. *Information for the Field Management of Invasive Alien Species in Korea*; Ministry of Environment: Seocheon, Korea, 2021.
16. Banks, N.C.; Paini, D.R.; Bayliss, K.L.; Hodda, M. The role of global trade and transport network topology in the human-mediated dispersal of alien species. *Ecol. Lett.* **2015**, *18*, 188–199. [CrossRef]
17. Chapman, D.; Purse, B.V.; Roy, H.E.; Bullock, J.M. Global trade networks determine the distribution of invasive non-native species. *Glob. Ecol. Biogeogr.* **2017**, *26*, 907–917. [CrossRef]
18. Levine, J.M.; D'Antonio, C.M. Forecasting biological invasions with increasing international trade. *Conserv. Biol.* **2003**, *17*, 322–326. [CrossRef]
19. Liebhold, A.M.; Work, T.T.; McCullough, D.G.; Cavey, J.F. Airline baggage as a pathway for alien insect species invading the United States. *Am. Entomol.* **2006**, *52*, 48–54. [CrossRef]
20. Tatem, A.J.; Rogers, D.J.; Hay, S.I. Global transport networks and infectious disease spread. *Adv. Parasitol.* **2006**, *62*, 293–343. [PubMed]
21. Bacon, S.J.; Bacher, S.; Aebi, A. Gaps in border controls are related to quarantine alien insect invasions in Europe. *PLoS ONE* **2012**, *7*, e47689. [CrossRef] [PubMed]
22. Kim, P.; Yeun, S.; An, H.; Kim, S.H.; Lee, H. Breeding Status and Management System Improvement of Pseudemys concinna and Mauremys sinensis Designated as Invasive Alien Turtles in South Korea. *Ecol. Resilient Infrastruct.* **2020**, *7*, 388–395.
23. Bradie, J.; Chivers, C.; Leung, B. Importing risk: Quantifying the propagule pressure–establishment relationship at the pathway level. *Divers. Distrib.* **2013**, *19*, 1020–1030. [CrossRef]
24. Blackburn, T.M.; Lockwood, J.L.; Cassey, P. The influence of numbers on invasion success. *Mol. Ecol.* **2015**, *24*, 1942–1953. [CrossRef]
25. Cardador, L.; Carrete, M.; Gallardo, B.; Tella, J.L. Combining trade data and niche modelling improves predictions of the origin and distribution of non-native European populations of a globally invasive species. *J. Biogeogr.* **2016**, *43*, 967–978. [CrossRef]
26. Simberloff, D. The role of propagule pressure in biological invasions. *Annual Review of Ecology, Evolution, and Systematics* **2009**, *40*, 81–102. [CrossRef]
27. Moore, B.A. *Alien Invasive Species: Impacts on Forests and Forestry—A Review*; Forestry Department and Forest Resource Division FAO, FAO Corporate Document Repository: Rome, Italy, 2005.
28. Early, R.; Bradley, B.A.; Dukes, J.S.; Lawler, J.J.; Olden, J.D.; Blumenthal, D.M.; Tatem, A.J. Global threats from invasive alien species in the twenty-first century and national response capacities. *Nat. Commun.* **2016**, *7*, 1–9. [CrossRef]
29. Liu, X.; Blackburn, T.M.; Song, T.; Li, X.; Huang, C.; Li, Y. Risks of biological invasion on the belt and road. *Curr. Biol.* **2019**, *29*, 499–505. [CrossRef]
30. Mack, R.N.; Simberloff, D.; Mark Lonsdale, W.; Evans, H.; Clout, M.; Bazzaz, F.A. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecol. Appl.* **2000**, *10*, 689–710. [CrossRef]
31. Xu, H.; Chen, K.; Ouyang, Z.; Pan, X.; Zhu, S. Threats of Invasive Species for China Caused by Expanding International Trade. *Environ. Sci. Technol.* **2012**, *46*, 7063–7064. [CrossRef]
32. Floerl, O.; Inglis, G.J. Starting the invasion pathway: The interaction between source populations and human transport vectors. *Biol. Invasions* **2005**, *7*, 589–606. [CrossRef]
33. Yemshanov, D.; McKenney, D.W.; Pedlar, J.H.; Koch, F.H.; Cook, D. Towards an integrated approach to modelling the risks and impacts of invasive forest species. *Environ. Rev.* **2009**, *17*, 163–178. [CrossRef]