Thesis for the Degree of Master of Science

Screening of Invasiveness Risks for the Current and Potential Non-Native Marine Fishes in South Korea

by

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by

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Abstract

Risk screening tools are increasingly being used to identify potential invasiveness risks of non-native species and to ensure their effective management. One of the risk screening tools, the Fish Invasiveness Screening Kit (FISK) has been successfully used in many risk assessment areas and has recently been upgraded to the new generic tool, which covers all aquatic species so called the Aquatic Species Invasiveness Screening Kit (AS-ISK). South Korea, with its international ports and indented coastline, has a semi-enclosed topography allowing the rapid spread of non-native species. In this thesis, it was aimed to assess the invasiveness risks of potential and existing non-native marine fish species for South Korea by using AS-ISK. With this purpose, 57 marine fishes were evaluated independently by one assessor and the threshold score, which reliably distinguished the species as potentially invasive (high risk) and potentially non-invasive (medium to low risk) was calculated as 5.5. Of the 57 species evaluated, 33 were classified as "low risk" while 6 were classified as "medium risk" and 18 as "high risk". While *Pterois miles* was determined as the highest score species with 29 points, *Hemitaurichthys multispinosus* was determined as the lowest score species with -14 points. The results suggested that further risk management studies should be conducted on the species that are particularly yielded higher scores for the conservation of the marine biodiversity of South Korea.

1 Introduction

Biological invasions in marine ecosystems disrupt the ecological balance and lead to biodiversity losses (Carlton and Geller 1993). This may cause ecological, environmental and economic problems. For instance, in the 1980s, after Comb Jelly *Mnemiopsis leidyi* was introduced in the Black Sea, it caused a loss of 240 million USD to the fishing industry since eggs of natural fish stocks were predated by this species. Another example is the bloom of non-native plankton species that crash shellfish aquaculture in New Zealand (POMRAC, 2007). The vast majority of these invasions in the marine environment originate from ballast waters, hydro-technical structures and biofouling of ships and it creates "novel" ecosystems (Hobbs *et al*., 2006). At the beginning of the 20th century, it was determined that the ballast waters of ships caused biological invasions, and in the 1880s new methods were developed by changing shipbuilding technology to prevent these invasions (Lutaenko *et al*., 2013). In addition, climate change, currents, and anthropogenic effects might also lead these invasions (Cartlon, 1996).

Non-native species may interact with native species, resulting in negative consequences such as predation, competition, parasitism, disease transport, and hybridization (Andrews, 1990; DINRAC, 2010). Some species are dangerous even for human health (Ruiz *et al*., 1997). However, it is a serious mistake to think that introduction of any new species results in an invasion in the recipient environment. Because only a small proportion of these introduced species may invade the environment by improving self-sustaining population and further expanded (Mack *et al*., 2000). It is extremely difficult to eliminate the invasive species that established populations in marine environments (Thresher and Kuris 2004). Thus, identification of invasive species is extremely important since even only single species may create huge damage to biodiversity and the economy (Molnar *et al*., 2008; Tarkan *et al*., 2013).

The introduction of non-native marine fish species into different regions by humans via intentional or unintentional may be carried out by aquaculture escapees, aquarium releases, transport or storage in ballast water (Hare and Whitfield, 2003). Invasions by marine fish species are very rare and the ecological effects of these invasions are known less than the effects of invasive freshwater fish species (Helfman, 2007). The introduction of these species are mostly limited to coastal bays, inland seas, and estuaries (Grosholz *et al*., 2000). Copp *et al*. (2005a) defined non-native invasive species as "*they spread, with or without the aid of humans, in natural or semi-natural habitats, producing a significant change in composition, structure, or ecosystem processes, or cause severe economic losses to human activities.*" The most known invasive marine fish species are Lionfish species (*Pterois miles* and *P. volitans*), which cause negative impacts both in the US (Hare and Whitfield, 2003) and in the Mediterranean Sea (Kletou *et al*., 2016). Additionally, Pufferfish species (*Lagocephalus spadiceus, L. sceleratus, L. suezensis*), *Siganus* species (*Siganus luridus* and *S. rivulatus*) and *Fistularia commersonii* are examples of well-known invasive marine fish species (Bilge *et al*., 2019).

The studies on invasive species on the Asian costs of the Pacific Ocean are relatively less than in the US and Australia (Seo and Lee, 2009). South Korea, with its international ports and indented coastline, has a semi-enclosed topography allowing the rapid spread of non-native marine fish species (DINRAC, 2010; Lutaenko *et al*., 2013). The first study about these fish species for South Korea was conducted by Seo and Lee (2009), and 52 marine fish species were listed as invasive for both Korea and Chinese coasts. Then, Shin (2010) considered 6 marine fish species as invasive in Korean coastal waters. Also, Henry and Reusser (2012) reported 13 marine fish species as non-indigenous marine or estuarine in the NOWPAP (Northwest Pacific Action Plan) region and Lutaenko *et al*. (2013) recorded 12 marine fish species as invasive in the same region. Hong *et al*. (2017) recorded three exotic *Anguilla* species (*A. anguilla*, *A. rostrata*, and *A. bicolor pacifica*) in Korean natural waters. Besides these, Kim *et al*. (2015) indicated the unusual poleward movement of *Pomacentrus coelestis* and *Microcanthus strigatus*, although they are natural species for Korea, according to FishBase (Froese and Pauly, 2019).

Risk screening tools are used to estimate the potential invasiveness of a non-native species introduced in a new environment (Daehler *et al*., 2004; Copp *et al*., 2016). It estimates based on a synthesis of information on the biological, ecological and developmental characteristics of the species studied and, on the biogeographic region in which the species is found (Pheloung *et al*., 1999). The characteristics of risk screening methods include information retrieval in question-answer format, use of simple computer programs, high-reliability estimations and flexibility of use for many different taxonomic groups (Kolar and Lodge, 2002). Risk scanning systems have a wide range of use and application strategies. These systems may be extremely useful to determine for many invasive and non-invasive species; besides they are fast and cost-free. Risk screening systems may also be very useful in recognizing the deficiencies related to the quality and reliability of the data in the literature (Copp *et al*., 2009). This plays an important role in determining management and research priorities. Even in some countries, risk screening systems are used to decide the import status of some alien species (Pheloung *et al*., 1999). More commonly, risk screening systems make initial assessments for the species studied and decide whether to perform risk analysis and management for future (Baker *et al*., 2008).

The first applications of species-risk analysis were tested by Pheloung *et al*. (1999) for the purpose of risk assessment of weed species in Australia. Later this application was modified for different organisms [e.g. Marine Fish Invasiveness Screening Kit (MFISK), Freshwater Fish Invasiveness Screening Kit (FISK), Marine Invertebrate Invasiveness Screening Kit (MI-ISK), Amphibian Invasiveness Screening Kit (Amph-ISK)]. Finally, Freshwater Fish Invasiveness Screening Kit (FISK v2) was updated and began to be used as a new tool called Aquatic Species Invasiveness Screening Kit (AS-ISK) (Copp *et al*., 2016). The main advantages of this new application are that it is designed to contain all aquatic organisms. This application has also been updated with 49 questions in FISK v2, making it more open and 55 questions with the addition of 6 extra climate change questions. The section with the questions added is discussed in a different section under the name of Climate Change Assessment (CCA) and it is designed as a separate section from the other 49 questions Basic Risk Assessment (BRA). As the FISK v2, it includes the reliability information of each question and the answers given to these questions. There is no change in the general structure of the questions. The questions are about the biogeography, invasion histories, biology and ecology of the species and whether they have undesirable features.

In marine fishes, AS-ISK was used for the first time on a Lessepsian fish, *Nemipterus randalli* in the Mediterranean Sea (Uyan et al., 2016) and then this tool was applied on the Lessepsian pufferfish species (*Lagocephalus guentheri*, *L. suezensis*, *L. spadiceus*, *L. sceleratus* and *Torguigener flavimaculasus*) (Filiz et al., 2017a) and *Pterois miles* (Filiz et al., 2017b) in the same risk assessment (RA) area (i.e. Gökova Bay/ Turkey). Finally, a threshold value was calculated using AS-ISK tool on 45 Lessepsian fish for the south-western coasts of Turkey (Bilge et al., 2019).

In this thesis study, it was aimed to determine the potential risk of possible and existing non-native marine fish species in the South Korean sea using AS-ISK. It is important, as it is the most comprehensive study about non-native marine fish species in the South Korea and AS-ISK has been used for the first time in the risk assessment area. It is expected that the results obtained may contribute to risk management of these species.

2. Material and Method

2. 1. Species Selection

Marine fish species might be introduced to South Korean sea in many pathways either intentionally or accidentally such as aquarium trade, aquaculture, live food fish market, ballast waters or global climate change effects. For the risk screening the studies, which were carried out considering all these pathways were determined by the literature and the species list was prepared accordingly. The majority of marine fish species listed in the first invasive species assessment for Korea and Chinese coasts (Seo and Lee, 2009) was evaluated in this study. Also, the species indicated in the reports for invasive marine species, both for the NOWPAP region (Shin *et al.*, 2010 and Lutaenko *et al.*, 2013) and for the whole of the North Pacific (Henry and Reusser, 2012) were also evaluated. The literature review was carried out for each species before the screening and the species that have conflicting information were not included in this study (e.g. *Takifugu rubripes*). Finally, in total 57 marine fish species representing 23 families were selected to be assessed for South Korean sea. These species were categorized based on three criteria: 1) those already presented in the RA area, 2) those that are not currently found in the RA area but are likely to occur in the future and 3) those not yet present in the RA area but important for the aquarium trade and aquaculture activities. 15.78% (9 species) of these species evaluated by one assessor was included in the first category, 66.66% (38 species) were included in the second category and %17.54 (10 species) were included in the third category.

2. 2. Questions and Statistic Analysis

Aquatic Species Invasiveness Screening Kit (AS-ISK v2.0.1) was used to identify the invasion potential of the selected species. AS-ISK is designed for minimum requirements (Roy et al., 2015) of European Union regulation on prevention and management of non-native species and it can be accessed and downloaded free at www.cefas.co.uk/nns/tools/ (Copp et al., 2016). The tool includes 55 questions (Table 1) collected under biogeographical/historical trait, biological/ecological characteristics and response to climate change, and the reliability information of these questions. The assessors must provide a response, justification and a level of confidence for each question, and the total numerical value is obtained from both Basic Risk Assessment (BRA) and Climate Change Assessment (CCA) score (respectively ranging from −20 to 68 and −32 to 80) when all the questions are answered (Copp *et al*., 2016). According to these values, a risk category is defined for the species assessed. These categories are defined as "low", "medium" and "high" risk (as invasive). If the value obtained is less than "1", the analyzed species is considered as no risk (Copp *et al*., 2016). While 49 of the AS-ISK's 55 questions relate to BRA of the species under investigation, the remaining 6 question (CCA) are related to how the characteristics of the species such as the risk of introduction, establishment, dispersal, and impacts will be changed under changing climatic conditions (Tarkan *et al*., 2017a, 2017b; Glamuzina *et al*., 2017). Climate questions were answered using the Köppen-Geiger climate classification system (Peel *et al*., 2007).

Receiver Operating Characteristic (ROC) analysis (Bewick *et al*., 2004) was used to assess the predictive ability of AS-ISK to discriminate between species "medium risk" and "high risk" (invasive). The classification *a priori* of each species was derived from two independent sources to ensure that the species required for the ROC analysis are classified in terms of an objectively perceived invasiveness (invasive or non- invasive); [Invasive Species Specialist Group database (ISSG) and Fishbase (Copp *et al*., 2009; Almeida *et al*., 2013; Puntila *et al*., 2013; Lawson *et al*., 2015; Li *et al*., 2017; Tarkan *et al*., 2017a, 2017b; Glamuzina *et al*., 2017; Tozludaş, 2018; Bilge *et al*., 2019). Also, the protection status of each species [Critically Endangered (CR), Data Deficient (DD), Endangered (EN), Least Concern (LC), Near Threatened (NT), Not Evaluated, Vulnerable (VU)] was provided through International Union for Conservation of Nature (IUCN). ISSG lists the fish introduced to different regions and gives an overview of the ecology, distribution, management, and impacts associated with them. FishBase is an internet source that classifies fish species as "threat to humans", "Traumatogenic", "Potential pest" or "Harmless". Statistically, a ROC curve is a susceptibility plot against 1-specificity (or, alternatively, sensitivity to specificity), in which the sensitivity and specificity cases in the present context are in proportions of invasive and non-invasive fish species, respectively. A measure of the accuracy of the calibration analysis is the area under the ROC curve (AUC). If the AUC is equal to 1.0 (that is, if the ROC curve consists of two straight lines, one vertical is between 0.0 and 0.1 and the other horizontal is between 0.1 and 1.1) then the test is 100% accurate, because both sensitivity and originality are 1.0. In other words, non-invasive species classified as invasive (false positives) or invasive species are classified as non-invasive (false negatives). Conversely, if the AUC is equal to 0.5 (that is if the ROC curve is a diagonal line between 0.0 and 1.1), then the test is 0% accurate because it cannot discriminate between the actual invasive species (true positives) and the actual non-invasive species (true negatives). As a result, the AUC value is between 0.5 and 1.0, and the closer the value is to 1.0, the better the ability of AS-ISK to differentiate between invasive and non-invasive species (Tarkan *et al*., 2017a; Tarkan *et al*., 2017b).

Following the ROC analysis, the best AS-ISK thresholds values (for BRA and CCA scores), which maximizes the true positive rate (true invasive species classified as invasive) and minimizes the false positive rate (true non-invasive species classified as invasive), was determined by using both Youden's J statistic (Youden, 1950) and the rate closest to the top- left part of the plot with perfect sensitivity or specificity (DeLong, 1988). Youden's index J captures the performance of the ROC analysis and is calculated as

$$J = \max \{\text{Sensitivity} + \text{Specificity} - 1\}$$

and is the probability of making an informed decision as opposed to a random guess (Glamuzina *et al*., 2017). In addition, an average ROC curve was generated and the boot-dependent security ranges of the specificities were calculated in the range of all sensitivity points.

Analyses were carried out with package pROC for R x64 v3.0.3 (R Development Core Team, 2015) using 2000 bootstrap replicates (Robin et al., 2011). As each response of AS-ISK for a given species was assigned to a level of confidence (1 = low, 2 = medium, 3 = high and 4 = very high), the 'confidence factor' (CF) was computed as:

$$\Sigma (CQ_i) / (4 \times 55) \ (i = 1., \ldots , 55)$$

where CQi is the certainty for question i, 4 is the maximum achievable value for certainty (i.e. ‘very certain’) and 55 is the total number of questions comprising the AS-ISK tool (Delong *et al*., 1988; Li *et al*., 2017; Tarkan *et al*., 2017b). The CF varies from a minimum of 0.25 (i.e., 55 questions with certainly score equal to 1) to a maximum of 1 (i.e., 55 questions with certainly score equal to 4).

Table 1. AS-ISK questions and guide to answer the questions

1. Has the taxon been the subject of domestication (or cultivation) for at least 20 generations?

The taxon must have been grown deliberately and subjected to substantial human selection for at least 20 generations, or it must be known to be easily reared in captivity (e.g. fish farms, aquaria or garden ponds, loch or fjord enclosures). This may be in the organism's native or introduced ranges.

2. Is the taxon harvested in the wild and likely to be sold or used in its live form?

Examples of this are: 1) lobsters, molluscs, fish etc. either immediately or grown on for human consumption; 2) fishes, crayfishes, plants, algae, etc. for use in captivity (e.g. private and public aquaria, garden ponds, ornamental gardens, zoos).

3. Does the taxon have invasive races, varieties, sub-taxa or congeners?

One or more of the species' varieties (races, morphs, etc.), or other species within the same genus, are known to be serious pests.

4. How similar are the climatic conditions of the RA area and the taxon's native range?

The intention of this question is to assess the likelihood of a taxon establishing self-sustaining populations in the RA area. If readily available, then a climate matching approach (e.g. Climex, GARP, Climatch) may be used (see summary in: Venette et al. 2010, BioScience 60: 349-362). If a climate matching model is not available, then make a 'best estimate' through consultation of the Köppen-Geiger climate region system (see: www.hydrol-earth-syst-sci-discuss.net/4/439/2007/hessd-4-439-2007.pdf) and/or local expertise.

5. What is the quality of the climate matching data?

The quality is an estimate of how complete are the data used to generate the climate analysis.

6. Is the taxon already present outside of captivity in the RA area?

Where possible, this should be assessed using documented scientific/expert evidence that the species has been found outside of captivity in the RA area.

7. How many potential vectors could the taxon use to enter in the RA area?

Consider all likely vectors of entry (unintentional and intentional) and categorize the response accordingly.

8. Is the taxon currently found in close proximity to, and likely to enter into, the RA area in the near future (e.g. unintentional and intentional introductions)?

There must be documented evidence of the organism being established in a neighboring river or lake drainage basin, coastal or marine region, etc. If the response to Q6 was 'Yes', then respond 'Not applicable' to this question.

9. Has the taxon become naturalized (established viable populations) outside its native range?

To be classed as naturalized, the taxon must have maintained self-sustaining populations for a minimum of 50 generations (for short generation-time species, i.e. ≤1 year) or 20 generations (for longer generation-time species, i.e. ≥2 years) in at least one location outside its native range.

10. In the taxon's introduced range, are there known adverse impacts to wild stocks or commercial taxa?

Where possible, this should be assessed using documented evidence of real impacts (i.e. decline of native species, disease introduction or transmission). In cases where circumstantial or opinion-based judgments are used, then the confidence level attributed to the response is expected to be 'Low' or not higher than 'Medium'.

11. In the taxon's introduced range, are there known adverse impacts to aquaculture?

Impacts on aquaculture impose a cost to control/manage the organism and/or result in productivity losses. If information is not available on the exact species but is for a closely-related species, then base the response on the known impacts of the related species.

12. In the taxon's introduced range, are there known adverse impacts to ecosystem services?

Where possible, this should be assessed using documented evidence that the organism has resulted in impacts to ecosystem services outside the RA area.

13. In the taxon's introduced range, are there known adverse socio-economic impacts?

Where possible, this should be assessed using documented evidence that the organism's introduction has led to adverse socio-economic impacts (e.g. amenities, livelihoods, cultural value, recreational activities/behaviors).

14. Is it likely that the taxon will be poisonous or pose other risks to human health?

Applicable if the organism's presence is known, for any reason, to cause discomfort or pain to humans.

15. Is it likely that the taxon will smother one or more native taxa (that are not threatened or protected)?

Some non-native species are known to suppress the growth of native species. For example, some non-native plants displace native species by expansive growth, which effectively smothers neighboring (native) plants.

16. Are there threatened or protected taxa that the non-native taxon would parasitize in the RA area?

This question is specifically aimed at identifying whether or not the introduced organism would become a predator or parasite of threatened or protected native species (e.g. local, regional, national red lists; Habitats & Species Directive Annexes; IUCN Red List, etc.).

17. Is the taxon adaptable in terms of climatic and other environmental conditions, thus enhancing its potential persistence if it has invaded or could invade the RA area?

'Adaptability' refers to the species' ability to overcome physiological or other barriers in order to establish self-sustaining populations, and thus distinguishes itself from 'tolerance' (Section 8 'Tolerance attributes'), which refer to the organism's ability to persist in harsh/extreme conditions. Output from climate matching can help answer this question, combined with the known versatility of the organism as regards climate region distribution.

18. Is the taxon likely to disrupt food-web structure/function in aquatic ecosystems it has or is likely to invade in the RA area?

Where possible, this should be assessed using evidence that the introduction of the species (whether or not it establishes a self-sustaining population) disrupts food-web structure and/or function.

19. Is the taxon likely to exert adverse impacts on ecosystem services in the RA area?

Various amenities (e.g. angling, water sports) and ecosystem products (e.g. drinking water supply, small-scale fisheries) in the RA area may be likely to be impacted. If information is not available on the exact species but is for a closely-related species, then base the response on the known impacts of the related species and attribute a ‘Low’ or ‘Medium’ confidence ranking to the response.

20. Is it likely that the taxon will host, and/or act as a vector for, recognized pests and infectious agents that are endemic in the RA area?

The main concerns are existing infectious agents, with the host being an additional vector of the infectious agent in the RA area.

21. Is it likely that the taxon will host, and/or act as a vector for, recognized pests and infectious agents that are absent from (novel to) the RA area?

The main concerns are non-native infectious agents, with the host being the original introduction vector of the disease in the RA area

22. Is it likely that the taxon will achieve a body size that will make it more likely to be released from captivity?

For example, although small-bodied marine and freshwaters fishes may be abandoned, large-bodied fishes are the major concern, as they can soon outgrow their holding facilities (e.g. aquaria or garden ponds). Similarly, some Amphibia and crustaceans achieve large sizes.

23. Is the taxon capable of sustaining itself in a range of water velocity conditions (e.g. versatile in habitat use)?

Species that are known to persist in both standing and flowing waters over a wide range of velocities (0 to 0.7 m per sec) should attract a 'Yes' response. This includes water velocities encountered by foulants attached to ship hulls, cooling-water intakes, etc.

24. Is it likely that the taxon's mode of existence (e.g. excretion of by-products) or behaviors (e.g. feeding) will reduce habitat quality for native taxa?

Where possible, this should be assessed using evidence that the organism's mode of existence (foraging behavior) results in an increase in suspended solids, reducing water clarity and thus habitat quality for native species (e.g. eco-engineer species such as common carp *Cyprinus carpio* in fresh waters, the Chinese mitten crab *Eriocher sinensis* in brackish waters).

25. Is the taxon likely to maintain a viable population even when present in low densities (or persisting in adverse conditions by way of a dormant form)?

There should be evidence of established populations of the organism persisting at low density in at least one location of its native and/or introduced range.

26. Is the taxon likely to consume threatened or protected native taxa in RA area?

This question is specifically aimed at identifying whether or not the introduced organism would exert an additional (non-natural) predation pressure on one or more native species that are threatened or protected (e.g. local, regional, national red lists; Habitats & Species Directive Annexes; IUCN Red List, etc.). This includes organisms that achieve large size quickly, thus allowing them to predate native species. Obligate carnivores are most likely to attract a 'Yes' response here, but some facultative species may become voracious predators when introduced to novel environments (e.g. red-eared terrapins *Trachemys scripta* elegans are classed as vegetarians in their native North American range but are known to be voracious predators when they inhabit ponds and lakes of Europe).

27. Is the taxon likely to sequester food resources (including nutrients) to the detriment of native taxa in the RA area?

This question is specifically aimed at identifying whether or not the introduced organism would exploit available resources (including nutrients, minerals, trace elements) at the expense of native species.

28. Is the taxon likely to exhibit parental care and/or to reduce age-at-maturity in response to environmental conditions?

Needs at least some documented evidence of the organism exhibiting parental care, or reducing its age at maturity when confronted by different environmental conditions, including population density, salinity variations, changes in community composition, etc.

29. Is the taxon likely to produce viable gametes or propagules (in the RA area)?

The conditions for maturation and reproduction must be available in the RA area in order to respond 'Yes' to this question.

30. Is the taxon likely to hybridize naturally with native taxa?

Where possible, this should be assessed using documented evidence of interspecific hybrids occurring, without assistance, under natural conditions.

31. Is the taxon likely to be hermaphroditic or to display asexual reproduction?

Needs at least some documented evidence of hermaphroditism/asexual reproduction in that Species, Genus or Family.

32. Is the taxon dependent on the presence of another taxon (or specific habitat features) to complete its life cycle?

Some species may require specialist incubators (e.g. unionid mussels used by bitterling Rhodeus spp.) or specific habitat features (e.g. coral reefs, hard substrata, fast-flowing water, particular species of plant or types of substrata) in order to reproduce successfully

33. Is the taxon known (or likely) to produce a large number of propagules or offspring within a short time span (e.g. <1 year)?

High fecundity and/or propagule/spore production is normally observed in medium-to-longer lived species.

34. How many time units (days, months, years) does the taxon require to reach the age-at-first-reproduction? [In the Justification field, indicate the relevant time unit being used.]

Time from hatching/parturition/germination to full maturity (i.e. active reproduction, not just presence of sexual organs). Please specify the number of time units by category relative to the taxonomic group being assessed.

35. How many potential internal pathways could the taxon use to disperse within the RA area (with suitable habitats nearby)?

Consider all likely dispersal pathways/vectors (unintentional and intentional) and provide a justification or comments for each pathway/vector in the response.

36. Will any of these pathways bring the taxon in close proximity to one or more protected areas (e.g. MCZ, MPA, SSSI)?

Following escape or release from captivity in the RA area. 'Close proximity' refers to whether or not the organism can conceivably reach the protected area or nature reserves (MCZ = marine conservation zone, MPA = marine protected area, SSSI = site of special scientific interest). E.g. for organisms that disperse passively, there would normally be a water flow between the organism's location and the protected area, thus facilitating invasion. For organisms with a short-to-moderate mobility capacity, determine whether there are stepping-stone habitats between the organism's location and the protected area.

37. Does the taxon have a means of actively attaching itself to hard substrata (e.g. ship hulls, pilings, buoys) such that it enhances the likelihood of dispersal?

Consider all possible means of attachment, e.g. does the organism have a specialized adaptation or morphological structure that facilitates its permanent or temporary attachment (e.g. sucking disc-like pectoral fins in some fish species of goby, e.g. Ponto-Caspian).

38. Is natural dispersal of the taxon likely to occur as eggs (for animals) or as propagules (for plants: seeds, spores) in the RA area?

There should be at least some documented evidence that eggs/spores/seeds are taken by water currents or displaced by other organisms either intentionally or not.

39. Is natural dispersal of the taxon likely to occur as larvae/juveniles (for animals) or as fragments/seedlings (for plants) in the RA area?

There should be at least some documented evidence that larvae/fragments/seedlings enter, or are taken by, water currents, or can move between water bodies via connections.

40. Are older life stages of the taxon likely to migrate in the RA area for reproduction?

There should be at least some documented evidence of migratory behavior or active dispersal mechanisms, even at a small scale (tens or hundreds of meters).

41. Are propagules or eggs of the taxon likely to be dispersed in the RA area by other animals?

For example, propagules or eggs that are dispersed by birds moving between water bodies or marine regions.

42. Is dispersal of the taxon along any of the pathways mentioned in the previous seven questions (7.01–7.07; i.e. both unintentional or intentional) likely to be rapid?

'Rapid' refers to any dispersal between the organism's starting point and the recipient location within the RA area that takes place in less than a calendar year for mobile organisms and less than five years for passive dispersing organisms.

43. Is dispersal of the taxon density dependent?

Where possible, this should be assessed using documented evidence of the organism spreading out or dispersing when its population density increases. The information may derive from either the organism's native or introduced range (or both).

44. Is the taxon able to withstand being out of water for extended periods (e.g. minimum of one or more hours) at some stage of its life cycle?

This includes organisms that produce or are some type of dormant form (e.g. spores, plant fragments) that is revitalized when it again enters an appropriate aquatic environment.

45. Is the taxon tolerant of a wide range of water quality conditions relevant to that taxon? [In the Justification field, indicate the relevant water quality variable(s) being considered.]

This is to identify taxa that can persist in cases of low oxygen and elevated levels of naturally-occurring or human-produced chemicals (e.g. ammonia).

46. Can the taxon be controlled or eradicated in the wild with chemical, biological, or other agents/means?

Where possible, this should be assessed using documented evidence of susceptibility of the organism (or taxonomically-related organisms e.g. congeners, sub-species, varieties, or taxonomic Family members) to chemical or other control agents/means.

47. Is the taxon likely to tolerate or benefit from environmental/human disturbance?

The growth and spread of some taxa may be enhanced by disruptions or unusual events (e.g. floods, spates, desiccation), especially human-generated impacts (e.g. rehabilitation/restoration works, engineering activities such as the construction of large hydropower installations, dams, reservoirs, etc.).

48. Is the taxon able to tolerate salinity levels that are higher or lower than those found in its usual environment?

Most notable here are diadromous species and other euryhaline organisms. Note that the presence of freshwater organisms in low salinity water bodies (e.g. Baltic Sea) does not indicate that they are euryhaline, so brackish/marine refers to a minimum salinity level of about 15‰.

49. Are there effective natural enemies (predators) of the taxon present in the RA area?

Potentially effective predators or control agents (e.g. infectious agents) of the organism (or related taxa) may be present in the RA area. Based on available knowledge (preferably peer-reviewed documents) of food webs (community composition) in the RA area, and respond accordingly.

50. Under the predicted future climatic conditions, are the risks of entry into the RA area posed by the taxon likely to increase, decrease or not change?

Where possible, use existing climate-change research outputs (otherwise use 'professional judgement', i.e. best guess) to indicate how future climatic conditions are likely to modify the risks of entry by the organism into the RA area.

51. Under the predicted future climatic conditions, are the risks of establishment posed by the taxon likely to increase, decrease or not change?

Where possible, use existing climate-change research outputs (otherwise use 'professional judgement', i.e. best guess) to indicate how future climatic conditions are likely to modify the risks of establishment (including the range of habitat types where the organism would be able to establish self-sustaining populations) within the RA area.

52. Under the predicted future climatic conditions, are the risks of dispersal within the RA area posed by the taxon likely to increase, decrease or not change?

Where possible, use existing climate-change research outputs (otherwise use 'professional judgement', i.e. best guess) to indicate how future climatic conditions are likely to modify the risks of the organism's dispersal within the RA area.

53. Under the predicted future climatic conditions, what is the likely magnitude of future potential impacts on biodiversity and/or ecological integrity/status?

Where possible, use existing climate-change research outputs (otherwise use 'professional judgement', i.e. best guess) to indicate how future climatic conditions are likely to modify the risks of potential adverse impacts by the organism within the RA area on biodiversity and/or ecological integrity, with specific reference to ecological status under the Water Framework Directive and/or the Marine Strategy Framework Directive.

54. Under the predicted future climatic conditions, what is the likely magnitude of future potential impacts on ecosystem structure and/or function?

Where possible, use existing climate-change research outputs (otherwise use 'professional judgement', i.e. best guess) to indicate how future climatic conditions are likely to modify the risks of potential adverse impacts by the organism within the RA area on ecosystem structure and function.

55. Under the predicted future climatic conditions, what is the likely magnitude of future potential impacts on ecosystem services/socio-economic factors?

Where possible, use existing climate-change research outputs (otherwise use 'professional judgement', i.e. best guess) to indicate how future climatic conditions are likely to modify the risks of potential adverse impacts by the organism within the RA area on ecosystem services and related socio-economic factors.

3. Results

Within the scope of the thesis study, AS-ISK scores of 57 marine fish species were assessed by one expert (Table 2). The area under curve (AUC) calculated according to the Receiver Operating Characteristic (ROC) analysis was calculated as 0.7397 (LCI = 0.5744, UCI = 0.9500) for the BRA (Figure 1) while this value was calculated as 0.7515 (LCI = 0.5912, UCI = 0.9117) for the CCA (Figure 2). The calculated AS-ISK scores of higher than 0.5, indicate that the analyzed species distinguish accurately between invasive and non-invasive species for the Risk Assessment Area (South Korea). Youden's J and closest point statistics gave the best thresholds of 5.5 for the BRA, 1.5 for CCA and these thresholds were used to distinguish between medium-risk species with scores within [1, 5.5[and high-risk species with scores within]5.5, 80]. Lastly, the species considered as low risk were those with BRA scores within [−20, 1[and CCA scores within [−32, 1[. (note that the inverse bracket indicating an open interval).

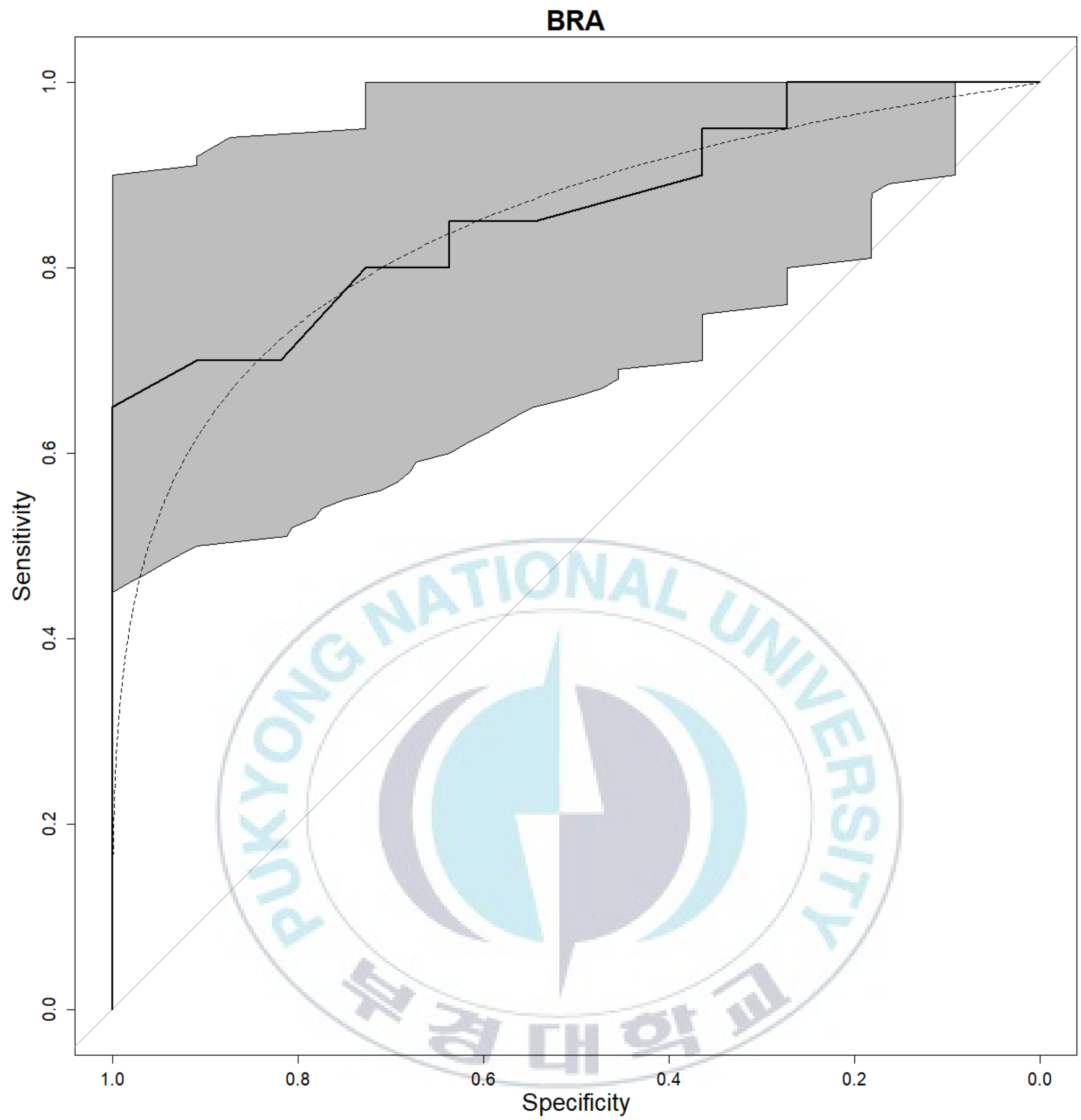

Figure 1 Figure 1. ROC curve at the AS-ISK of the Basic Risk Assessment (BRA) of the 57 non-native marine fish species in South Korea. Sensitivity (%) = the probability that invasive species are correctly identified as invaders; Specificity (%) = probability of non-invasive species to be identified as non-invasive species. Slope area = accuracy of analysis, 1 = 100% accuracy; 0.5 = 0% accuracy

BRA is based on the threshold value, between (1) low-risk [-20, 1[, (2) medium-risk [1, 5.5[and (3) high-risk]5.5, 68].

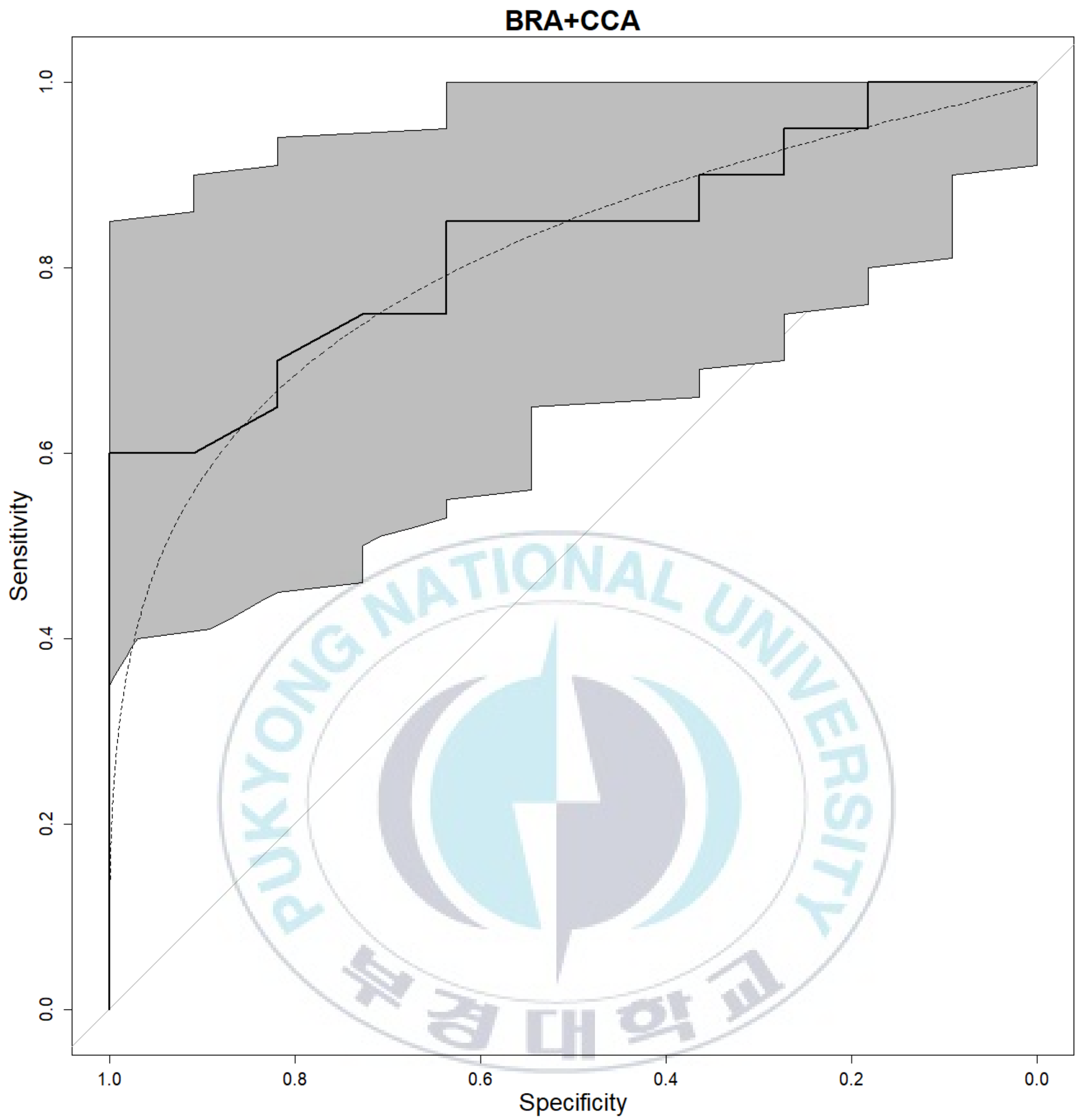

Figure 2 ROC curve at the AS-ISK of the Climate Change assessment (CCA) of the 57 non-native marine fish species in South Korea. Sensitivity (%) = the probability that invasive species are correctly identified as invaders; Specificity (%) = probability of non-invasive species to be identified as non-invasive species. Slope area = accuracy of analysis, 1 = 100% accuracy; 0.5 = 0% accuracy.

CCA is based on the threshold value, between (1) low risk [-32, 1[, (2) medium risk [1, 1.5[, and (3) high risk]1.5, 80].

According to BRA, 33 species (57.89%) of 57 were of low risk, 6 species (10.52%) were of medium risk and the remaining 18 species (31.57%) [(the species belonging to Anguillidae (2 species), Atherinopsidae (1 species), Carangidae (1 species), Cichlidae (1 species), Holocentridae (1 species), Latidae (1 species), Megalopidae (1 species), Moronidae (2 species), Paralichthyidae (2 species), Salmonidae (1 species), Sciaenidae (1 species), Scophthalmidae (1 species), Scorpaenidae (1 species), Siganidae (1 species), Sparidae (1 species) families] were at high-risk (Table 2). The high-risk species are Devil firefish, *Pterois miles*; White perch, *Morone americana*; Red drum, *Sciaenops ocellatus*; Marbled spinefoot, *Siganus rivulatus*; Redcoat, *Sargocentron rubrum*; Sunshine bass, *Morone saxatilis*; Blackchin tilapia, *Sarotherodon melanotheron*; Argentinian silverside, *Odontesthes bonariensis*; Barramundi, *Lates calcarifer*; European eel, *Anguilla anguilla*; Atlantic salmon, *Salmo salar*; American eel, *Anguilla rostrate*; Gilthead seabream, *Sparus aurata*; Turbot, *Scophthalmus maximus*; Southern flounder, *Paralichthys lethostigma*; White trevally, *Pseudocaranx dentex*; Summer flounder, *Paralichthys dentatus*; Tarpon, *Megalops atlanticus*. The species with the lowest BRA score is Many-spined butterflyfish, *Hemitaurichthys multispinosus* with -14 scores (Table 2).

Similarly, according to CCA, 31 species (54.38%) of 57 were of low risk, 4 species (7.01%) were of medium risk and 22 species (38.59%) were of high risk were determined. The high-risk species are Devil firefish, *Pterois miles*; White perch, *Morone americana*; Red drum, *Sciaenops ocellatus*; Marbled spinefoot, *Siganus rivulatus*; Redcoat, *Sargocentron rubrum*; Blackchin tilapia, *Sarotherodon melanotheron*; Argentinian silverside, *Odontesthes bonariensis*; Barramundi, *Lates calcarifer*; Gilthead seabream, *Sparus aurata*; Sunshine bass, *Morone saxatilis*; White trevally, *Pseudocaranx dentex*; Tarpon, *Megalops atlanticus*; Senegale sole, *Solea senegalensis*; Common sole, *Solea solea*; American eel, *Anguilla rostrate*; Brown-marbled grouper, *Epinephelus fuscoguttatus*; European eel, *Anguilla anguilla*; Southern flounder, *Paralichthys lethostigma*; Turbot, *Scophthalmus maximus*; Atlantic salmon, *Salmo salar*; Copperband butterflyfish, *Chelmon rostratus*; Summer flounder, *Paralichthys dentatus*. The species with the lowest CCA score is Many-spined butterflyfish, *Hemitaurichthys multispinosus* with -14 scores (Table 2). On the other hand, the highest score among the species affected negatively on the global climate change scenarios was *Salmo salar* with -10 delta score (Table 2).

The CCA scores were lower than BRA scores for the 10 species evaluated, higher for 45 species, and equal for the 2 species (Table 2). The majority of species with lower CCA scores (8 species) is temperate zone species (*Anguilla rostrata* and *Paralichthys lethostigma* species are subtropical species). Species with higher CCA scores are mostly (32 species) tropical species (remaining 11 subtropical and 2 temperate species). One of the species with equal BRA and CCA scores is deep-water species (*Prognathodes guyotensis*) and the other subtropical species (*Hemitaurichthys multispinosus*).

Of the 57 species assessed according to the results of the "*a priori*" assigned from independent sources, 40 were "non-invasive" and the remaining 17 were "invasive". According to the AS-ISK results classified 61.11% of invasive marine fish species and 84.61% of non-invasive marine fish species correctly. Most of the species classified *a priori* as invasive (11 species) were ranked as "high risk" (invasive), 1 species was "medium risk" and 5 species were "low-risk". Most of the species classified *a priori* as non-invasive (28 species) were ranked as "low risk", 5 species were "medium risk" and 7 species were "high risk" (invasive).

The majority of species (41) assessed in this study were classified as "Least Concern" in the "Red List" created by IUCN (International Union for Conservation of Nature and Natural Resources). 10 of the species considered to be "high risk" (invasive) were classified as "Least Concern (LC)" 1 were classified as Critically Endangered (CR), 1were classified as Endangered (EN), 1 were classified as Near Threatened (NT), 4 were classified as Not Evaluated, 1 were classified as Vulnerable (VU).

When the species in the study were analyzed according to the criteria, 4 of the species in the first category were listed as high-risk, 2 of them were medium-risk and 3 of them were low-risk. In the second category, 10 species are listed as high-risk, 2 are medium-risk and 26 are low-risk. In the 3rd category, 4 species were classified as high-risk, 2 medium-risk and 4 low-risk. The highest score belongs to Red drum, *Sciaenops ocellatus* (BRA = 24.5) in category 1, White perch, *Morone americana* in category 2 (BRA = 27.5) and the highest score in category 3 belongs to Devil firefish, *Pterois miles* (BRA = 29) (Table 2).

Mean confidence level for all Qs (CL_{Total}) was 2.730 ± 0.01 SE, for the BRA Qs (CL_{BRA}) 2.854 ± 0.01 SE, and for the CCCA Qs (CL_{CCA}) 1.74 ± 0.02 SE. Similarly, mean values for CF_{Total}= 0.694 ± 0.002 SE, CF_{BRA}= 0.726 ± 0.002 and CF_{CCA}= 0.434 ± 0.007.

Table 2 Non-native marine fish species assessed using AS-ISK for South Korea

Taxon name	Common name	Criterion	Invasiveness	IUCN	Climate	BRA		BRA+CCA		CL	CF
						Score	Risk	Score	Risk	Total	Total
Acipenser gueldenstaedtii	Danube sturgeon	1	N	Critically Endangered (CR)	Temperate	4	M	0	L	2.7	0.7
Acipenser nudiventris	Fringebarbel sturgeon	2	N	Critically Endangered (CR)	Temperate	1	M	-5	L	2.7	0.7
Amphiprion akallopisos	Skunk clownfish	3	N	Least Concern (LC)	Tropical	-4	L	0	L	2.8	0.7
Amphiprion ephippium	Saddle anemonefish	3	N	Least Concern (LC)	Tropical	-4	L	0	L	2.8	0.7
Amphiprion sandaracinos	Yellow clownfish	2	N	Least Concern (LC)	Tropical	-4	L	0	L	2.8	0.7
Amphiprion sebae	Sebae anemonefish	2	N	Not Evaluated	Tropical	-4	L	0	L	2.8	0.7
Anguilla anguilla	European eel	2	N	Critically Endangered (CR)	Temperate	14	H	6	H	2.8	0.7
Anguilla rostrata	American eel	2	N	Endangered (EN)	Subtropical	10.5	H	8.5	H	2.9	0.7
Chelmon marginalis	Margined coralfish	3	N	Least Concern (LC)	Tropical	-8	L	-4	L	2.8	0.7
Chelmon muelleri	Blackfin coralfish	1	N	Least Concern (LC)	Tropical	-7	L	-3	L	2.8	0.7
Chelmon rostratus	Copperband butterflyfish	2	N	Least Concern (LC)	Tropical	-4	L	2	H	2.7	0.7
Chelmonops curiosus	Western talma	2	N	Least Concern (LC)	Subtropical	-8	L	-4	L	2.8	0.7
Chelmonops truncatus	Eastern talma	2	N	Least Concern (LC)	Temperate	-10	L	-6	L	2.8	0.7
Ctenochaetus binotatus	Twospot surgeonfish	2	Y	Least Concern (LC)	Tropical	-6	L	0	L	2.8	0.7
Ctenochaetus hawaiiensis	Chevron tang	2	N	Least Concern (LC)	Tropical	-5	L	1	M	2.7	0.7
Ctenochaetus marginatus	Striped-fin surgeonfish	2	N	Least Concern (LC)	Tropical	-8	L	-4	L	2.8	0.7
Ctenochaetus truncatus	Indian gold-ring bristle-tooth	2	N	Least Concern (LC)	Tropical	-8	L	-4	L	2.8	0.7
Epinephelus fuscoguttatus	Brown-marbled grouper	2	Y	Vulnerable (VU)	Tropical	4	M	8	H	2.9	0.7
Genicanthus bellus	Ornate angelfish	2	N	Least Concern (LC)	Tropical	-5	L	-1	L	2.8	0.7
Genicanthus watanabei	Blackedged angelfish	2	N	Least Concern (LC)	Tropical	-4	L	0	L	2.8	0.7
Hemitaurichthys multispinosus	Many-spined butterflyfish	2	N	Least Concern (LC)	Subtropical	-14	L	-14	L	2.8	0.7
Hemitaurichthys thompsoni	Thompson's butterflyfish	2	N	Least Concern (LC)	Tropical	-5	L	-1	L	2.7	0.7
Hemitaurichthys zoster	Brown-and-white butterflyfish	2	N	Least Concern (LC)	Tropical	-3	L	1	M	2.7	0.7
Heniochus intermedius	Red Sea bannerfish	2	Y	Least Concern (LC)	Tropical	-10	L	-6	L	2.8	0.7
Heniochus pleurotaenia	Phantom bannerfish	2	N	Least Concern (LC)	Tropical	-8	L	-4	L	2.8	0.7
Heniochus singularius	Singular bannerfish	2	N	Least Concern (LC)	Tropical	-5	L	1	M	2.8	0.7
Heniochus varius	Horned bannerfish	2	N	Least Concern (LC)	Tropical	-6	L	0	L	2.8	0.7
Holacanthus tricolor	Rock beauty	2	Y	Least Concern (LC)	Tropical	-11	L	-7	L	2.7	0.7

Johnrandallia nigrirostris	Blacknosed butterflyfish	2	N	Least Concern (LC)	Tropical	-10	L	-6	L	2.8	0.7
Lates calcarifer	Barramundi	2	N	Not Evaluated	Tropical	15	H	23	H	2.9	0.7
Megalops atlanticus	Tarpon	3	Y	Vulnerable (VU)	Subtropical	6	H	12	H	2.7	0.7
Morone americana	White perch	2	Y	Least Concern (LC)	Temperate	27.5	H	37.5	H	2.7	0.7
Morone saxatilis	Sunshine bass	3	Y	Least Concern (LC)	Temperate	19.5	H	13.5	H	2.8	0.7
Odontesthes bonariensis	Argentinian silverside	1	Y	Not Evaluated	Subtropical	17.5	H	25.5	H	2.6	0.7
Parachaetodon ocellatus	Sixspine butterflyfish	2	N	Least Concern (LC)	Tropical	-5	L	1	M	2.8	0.7
Paralichthys dentatus	Summer flounder	2	Y	Least Concern (LC)	Temperate	6	H	2	H	2.9	0.7
Paralichthys lethostigma	Southern flounder	2	N	Near Threatened (NT)	Subtropical	8	H	4	H	2.9	0.7
Pomacanthus maculosus	Yellowbar angelfish	2	Y	Least Concern (LC)	Tropical	-5	L	-1	L	2.7	0.7
Prognathodes aculeatus	Longsnout butterflyfish	2	N	Least Concern (LC)	Tropical	-6	L	-2	L	2.7	0.7
Prognathodes aya	Bank butterflyfish	2	N	Least Concern (LC)	Subtropical	-6	L	-2	L	2.8	0.7
Prognathodes brasiliensis	-	2	N	Least Concern (LC)	Subtropical	-6	L	-2	L	2.7	0.7
Prognathodes dichrous	Bicolor butterflyfish	2	N	Least Concern (LC)	Tropical	-6	L	-2	L	2.8	0.7
Prognathodes falcifer	Scythemarked butterflyfish	1	N	Least Concern (LC)	Subtropical	-10	L	-6	L	2.8	0.7
Prognathodes guyotensis	-	3	N	Data deficient (DD)	Deep-water	-6	L	-6	L	2.7	0.7
Pseudocaranx dentex	White trevally	3	N	Least Concern (LC)	Tropical	7	H	13	H	2.8	0.7
Pterois miles	Devil firefish	3	Y	Least Concern (LC)	Tropical	29	H	39	H	2.9	0.7
Salmo salar	Atlantic salmon	2	Y	Least Concern (LC)	Temperate	13	H	3	H	2.9	0.7
Sargocentron rubrum	Redcoat	2	Y	Least Concern (LC)	Subtropical	22.5	H	30.5	H	2.6	0.6
Sarotherodon melanotheron	blackchin tilapia	1	Y	Not Evaluated	Tropical	18	H	26	H	2.9	0.7
Sciaenops ocellatus	Red drum	1	N	Least Concern (LC)	Subtropical	24.5	H	32.5	H	2.8	0.7
Scophthalmus maximus	Turbot	2	N	Not Evaluated	Temperate	8	H	4	H	2.8	0.7
Siganus rivulatus	Marbled spinefoot	2	Y	Least Concern (LC)	Subtropical	23	H	31	H	2.7	0.7
Solea senegalensis	Senegale sole	3	N	Data deficient (DD)	Tropical	5	M	11	H	2.8	0.7
Solea solea	Common sole	1	N	Data deficient (DD)	Subtropical	4	M	10	H	2.9	0.7
Sparus aurata	Gilthead seabream	1	Y	Least Concern (LC)	Subtropical	10	H	18	H	2.5	0.6
Verasper moseri	Barfin flounder	3	N	Not Evaluated	Temperate	5	M	-1	L	2.9	0.7
Zebrasoma flavescens	Yellow tang	1	Y	Least Concern (LC)	Tropical	-4	L	0	L	2.7	0.7

Criteria: 1) those already presented in the RA area, 2) those that are not currently found in the RA area but are likely to occur in the future and 3) those not yet present in the RA area but important for the aquarium trade and aquaculture activities. The selection criteria for each species, the status of the invasion (www.issg.org and www.fishbase.org) and the protection status (www.iucnredlist.org) were determined (N= non-invasive; Y= invasive). BRA values calculated according to the threshold value of 5.5; (1) low-risk (L) [-20, 1], (2) medium-risk (M) [1, 5.5] and (3) high-risk (H) [5.5, 68]. CF: certainty factor, CL = confidence level

4. Discussion

This thesis provides the most comprehensive study on non-native marine fish species in South Korea. This is also the first assessment using AS-ISK on marine fish in South Korea.

According to the results of the study, the species with the highest score (BRA:29) was Devil firefish, *Pterois miles*. Although it has not been recorded in the risk assessment area (South Korea), it has been evaluated because it is the most successful invasive marine fish on a global scale (Filiz et al. 2017b). This species, which is very popular in the aquarium sector, has been reported to be introduced to the United States (e.g. the Gulf of Mexico and the Caribbean Sea) via this pathway and causes serious damage to the diversity and functioning of native species (Albins and Hixon, 2008; Morris and Whitfield, 2009; Green et al. 2012). In addition, the species has been reported to increase rapidly after entering the Mediterranean Sea through the Suez Canal, causing negative effects (Kletou et al., 2016). *P. miles* reaches sexual maturity in as little as 1 year (Morris and Akins, 2009), they can form large populations whereby high fecundity (Draman, 2018) and can rapidly change ecosystem structure and function by feeding on small fish (Muñoz et al. 2011). However, low salinity tolerance, survival at different depths and long-term fasting properties enable these species to succeed in invasion (Kimball et al., 2004). In addition, the poisonous of the species may negatively affect economically important commercial activities such as tourism (Lozano, 2013). The invasiveness of *P. miles* was assessed for the Mediterranean Sea by using AS-ISK and classified as high risk (Filiz et al., 2017b; Bilge et al., 2019).

The two Morone species (*M. americana* and *M. saxatilis*) assessed in this study were classified as high-risk (invasive) with BRA: 27.5 and 19.5 respectively. Of these, White perch, *Morone americana* is a hybrid species of (*M. saxatilis* and *M. chrysops*) (Safner et al., 2013; Kizak and Güner, 2014) and can occur in marine, freshwater, and brackish environments (Able and Fahay, 2010). Since it is known to be an invasive species in some regions [e.g. Kerr Reservoir- Virginia (Harris, 2006); Lake Kaw- Oklahoma (Kuklinski, 2015)], where it was introduced, it was considered appropriate to evaluate it for the risk assessment area. Most of the diets of this species consist of zooplankton and therefore may adversely affect the habitats to which they are introduced. For example, *Daphnia* species have been reported to decrease after their introduction in Lake Champlain (Couture and Watzin 2008). Another important component of their diet is fish eggs. This feeding behavior may also have negative effects on native species (Schaeffer and Margraf 1987). Finally, *M. america* is known to compete with native species for food. For example, it was reported that the population of *Perca flavescens* decreased after their introduction to Lake Erie (North America) (Parrish and Margraf, 1990). The invasiveness of *M. americana* has previously been assessed in different regions of the world using different risk screening tools. Vilizzi and Copp (2013), assessed the species by using FISK for Murray-Darling Basin (Southeast Australia) and classified it as moderately high-risk. Tarkan et al. (2014), assessed the species by using FISK for Thrace and Anatolia (Turkey) and classified as medium risk. Pria et al. (2016) assessed the species by using FISK for Croatia and classified as medium risk. Tarkan et al. (2017a) assessed the species by using AS-ISK for inland waters of Turkey and classified as moderately high risk. Finally, Tozludaş (2018), assessed the species by using AS-ISK for inland waters of Turkey and classified as high risk.

Striped bass, *Morone saxatilis,* such as *M. Americana* has been introduced to different regions for aquaculture purposes (Holčík, 1991). This species listed as invasive for both Korea and Chinese coasts by Seo and Lee (2009) and it was considered as invasive for Korea by Shin (2010). This species was established on the Chinese coast (Yellow Sea) (Henry and Reusser 2012; Lutaenko et al., 2013). Since they can live in marine, freshwater and brackish environments (Riede, 2004), their impact areas may be extensive. Female individuals can produce an average of 160,000 eggs per kilogram of body weight (Hodson 1989). It has been reported to cause a decrease in clupeids species in different regions (Bailey, 1975). *M. saxatilis* assessed by using AS-ISK for inland waters for Turkey by Tozludaş (2018) and classified as medium risk.

Red drum, *Sciaenops ocellatus* was introduced for aquaculture into South Korea (Oh et al. 2002) and it has been listed as an invasive for Korea and Chinese coasts by Seo and Lee (2009) and was considered as invasive for Korea by Shin (2010). It has established in both Singapore (Henry and Reusser 2012) and Thailand (Liao et al., 2010). The species is reported to cause poisoning when its meat is consumed as raw (Landsbrg, 1993; Lio, et al., 2009; Stunz, et al., 2002). *S. ocellatus* assessed by using AS-ISK for inland waters for Turkey by Tozludaş (2018) and classified as high risk. This is also were classified high risk with BRA: 24.5.

Marbled spinefoot *Siganus rivulatus*, which caused the algae communities to decrease significantly after introduction to the Mediterranean Sea (Sala et al. 2011), was classified as high risk in the AS-ISK study conducted by Bilge *et al*. (2019). Although it is not introduced in the risk assessment area, it is evaluated as a species used in aquaculture and were classified as high risk (BRA: 23). As a matter of additional concern, it has dorsal and anal fins that contain such poison (Froese and Pauly, 2019).

Redcoat, *Sargocentron rubrum*, has been associated with a reduction in the number of native indigenous groupers and sparids in the Mediterranean Sea. It is observed in the caves with *Apogon imberbis*, which is a native the Mediterranean sea species, and it is estimated that organic matter may increase their transfer to these caves in which they live and cause negative effects on invertebrate fauna (Otero et al., 2013). The species classified as high-risk (BRA: 22.5) in this study was also classified as high-risk in the AS-ISK study conducted by Bilge *et al*. (2019) in the Mediterranean Sea.

Blackchin tilapia, *Sarotherodon melanotheron* was associated with the depletion of aquatic plants in the regions where it is recorded (Molnar 2008). It is categorized as potential pest in FishBase (Froese and Pauly, 2019). Since they can tolerate high salinity, they are found in lagoons (Froese and Pauly, 2019). Parental care is observed in male individuals (Shaw and Aronson, 1954), which increases the chances of survival of the offspring, allowing the species to form a population in a short period of time. This species was classified as medium risk in FISK study for peninsular Florida (Lawson et al., 2015). In this study, it was classified as high-risk with BRA: 18.

Argentinian silverside, *Odontesthes bonariensis* introduced in Japan in 1966, was established in this region (Henry and Reusser, 2012). In Peru and Chile, where it was introduced, it caused a reduction in native species (Jacobsen and Dangles, 2017). It is classified as a potential pest for humans in FishBase (Froese and Pauly, 2019). This species can live in lentic and lotic waters in many different habitats such as rivers, streams, canals, lakes, reservoirs, estuaries and coastal lakes (Avigliano and Volpedo 2013). Argentinian silverside can hybridize with other species of the genus Ontestes both in the natural environment and under captivity (García et al., 2014). Although it is not introduced in the risk assessment area, it was assessed because it is an invasive species and was classified as high risk (BRA: 17.5) in these studies.

Barramundi, *Lates calcarifer* is a popular fish both in aquaculture and fisheries as well as in popular gamefish. It is also used in public aquariums. It can live in both marine and freshwater environments. It has the ability to change the spawning period in response to water temperatures (FAO, 2019). They exhibit hermaphroditism by becoming females through changing sex between the ages of 6-8 years (FAO, 2019) and can produce an estimated 2.3 million per kg of female (Froese and Pauly, 2019). The species was responsible for the destruction of cichlid species in Lake Victoria (Morgan, 2004). Seo and Lee (2009) listed the species as invasive for Korea and Chinese coasts. It was classified as high risk (BRA:15).

European eel, *Anguilla anguilla* has been recorded in the natural waters in Korea (Hong et al., 2017). It has also been reported to be established in Japan (Henry and Reusser, 2012). The species was listed by Seo and Lee (2009) as an invasive for Korea and Chinese coasts and was considered as an invasive species in the NOWPAP region by Lutaenko et al. (2013). It is stated that these species are fed on young salmon and that it can compete with their adults for food (McCosker 1989, Coad 1995). Eels can cause losses in fishing by releasing commercial species attached to fish nets (Coad 1995). They may cause new diseases to emerge in the new habitats they are introduced (McCosker 1989). Many diseases have been reported on European eels (Froese and Pauly 2009). They can form hybrids with *Anguilla rosrata* (Albert et al. 2006). (Froese and Pauly, 2019). This species assessed by using AS-ISK for Lake Marmara (Turkey) by Tarkan et al. (2017b) and classified as low risk. This species is classified as medium risk in the Iberian Peninsula (Almeida et al., 2013), in Croatia and Slovenia (Pria et al., 2016) and classified as moderately high risk in Lake Balaton (Hungary) (Ferincz et al., 2016). Finally it was classified high risk (BRA: 14) in this study.

American eel, *Anguilla rostrata* was recorded in the natural waters in South Korea too (Hong et al. 2017). This species, which can live in both marine, freshwater and brackish environments (Froese and Pauly, 2019). *A. rostrata*, which has not been previously evaluated by any risk screening tool, has been reported in natural waters in Taiwan (Han et al., 2002) and in Japan (Miyai et al., 2004). Also, it was listed as invasive by Lutaenko et al. (2013) in the NOWPAP region. It was classified high risk (BRA: 10.5) in this study.

Atlantic salmon, *Salmo salar*, was listed by Seo and Lee (2009) as invasive on the coasts of Korea and Chinese, it was listed as invasive Korea by Shin (2010) and in NOWPAP region by Lutaenko et al. (2013). It is not known whether the species has established wild populations in these regions (Henry and Reusser 2012). It was stated that individuals escaping from breeding cages can compete with native species and infect the disease (Naylor et al., 2005). A large number of cultured salmonids are released or escaped in the wild and may establish significant proportions of wild salmonid populations in freshwater and marine, and may occur significant concern for the suitability and productivity of these populations (Hindar et al. 2006). Farm-grown *S. salar* also hybridizes with wild salmonid thereby altering the diverse of genetic variability and frequency and alleles in gene stocks, reducing the ability of wild animals to survive in wildlife (Leániz and Verspoor 1989; Thorstad et al, 2006). This species was reported in the "100 invasive species" list prepared in 2004 by the Oregon Invasive Species Council (Nugent et al. 2005). They can be found in marine, freshwater and brackish environments (Froese and Pauly, 2019). *S. salar* is classified as medium risk in all risk screenings. These studies were conducted by Almeida et al. (2013) in the Iberian Peninsula, by Tarkan et al. (2014), Tarkan et al. (2017) and Tozludaş (2018) in Turkey and by Perdikaris et al. (2016) in Greece. But in this study, it was classified as high risk (BRA: 13)..

Gilthead seabream, *Sparus aurata*, is a species used in both fisheries and aquaculture activities. It is also popular as a gamefish. It was thought that individuals escape from fish farms may adversely affect the genetic diversity of wild populations (Miggiano et al. 2005). They can occur in both marine and brackish environments (Froese and Pauly, 2019). Since it is a very voracious predator, it is worried that it may cause a decrease in other species cultivated (such as the Atlantic and Pacific salmon in British Columbia and Chile, or Channel fish, Asian black carp and many tilapia species in the United States) (Balart et al., 2009). Since it is a widely used species in aquaculture activities, risk assessment has been carried out for South Korea and it was classified as high risk (BRA: 10) in this study.

Turbot, *Scophthalmus maximus* was introduced in China (Chavanich et al. 2010) and Korea (Seo and Lee, 2009), but it is not known whether it was established in the wild (Hendy and Reusser, 2012). This species, which can live in both marine and brackish environments, is capable of reproduction in various salinity (Florin and Höglund, 2007). It was classified as high risk (BRA: 8) in this study.

Southern flounder, *Paralichthys lethostigma* is cultivated in China, but it is not known whether it was established (Henry and Reusser, 2012). This species, which can be found in both marine and brackish environments, has been listed as invasive by Lutaenko et al. (2013) for the NOWPAP region. It was caused *Neoheterobothrium hirame* (philometrid parasite) to move to Japan (Henry and Reusser 2012). It was classified as high risk (BRA: 8) in this study.

Summer flounder, *Paralichthys dentatus* is cultivated in China, but it is not known whether it was established in a natural environment (Henry and Reusser 2012). *P. dentatus* was evaluated by Lutaenko et al. (2013) as an invasive species for the NOWPAP region. The natural stock of the species lives only in a local area (from the Gulf of South Maine to South Carolina and occasionally in Florida) in the World (Bigelow and Schroeder 2002). Summer flounder is a highly irregular series of spawners that produce thousands to millions of pelagic eggs (Packer et al. 1999). It was classified as high risk (BRA: 6) in this study.

White trevally, *Pseudocaranx dentex* was recorded from Jeju Island-South Korea (Kim ve Song, 2014), this species was listed as invasive for Korea by Seo and Lee (2009) for both Korea and China coasts. Also, this was considered as invasive by Shin (2010) for Korea. It was classified high risk (BRA: 7) in this study.

Tarpon, *Megalops atlanticus* can live in both marine, freshwater and brackish environments (Froese and Pauly, 2019). Fishbase has reported Ciguatera poisoning (Froese and Pauly, 2019). It is stated that in case of its distribution and reproduction in the Pacific Ocean, it can be invasive, compete with native species and change their genetic structure (Neira and Acero, 2016). It is a species with high fecundity. For example, a female individual of 203 cm can produce more than 12 million eggs (Garcia and Solano, 1995). They can breathe atmospheric oxygen and thus tolerate oxygen-free environments (Geiger et al. 2000; Wells et al. 2003). It was classified as high risk (BRA: 6) in this study.

In this study, it is not a coincidence that 17 of the 18 species classified as high risk are used in both aquaculture and fisheries. Marine fish species can be intentionally or accidentally introduced to a new habitat through the aquarium trade, aquaculture activities, fishing, live food fish market, ballast waters or global climate change, and the most potentially important of this introduction are aquaculture and fisheries (Seo and Lee, 2009). The possibility of introducing non-native marine fish species to the Asian coasts is expected to increase with the expansion both fisheries and aquaculture industries and it is thought that there will be a lot of negative effects if it will not be taken a measure (Bang 2004).

Since medium risk does not mean risk-free, it is also useful to consider species classified as medium risk, too (Tarkan et al., 2017a). In this thesis, all species classified as medium risk are used in aquaculture. *Solea* species (*Solea senegalensis* and *S. solea*) classified as medium risk were evaluated by Lutaenko et al. (2013) as an invasive species for the NOWPAP region. Barfin flounder, *Verasper moseri* was considered as invasive by Seo and Lee (2009) for the Korean and Chinese coasts and was considered as invasive by Lutaenko et al. (2013) for the NOWPAP region. Among the *Acipenser* species evaluated in this study, Danube sturgeon, *Acipenser gueldenstaedtii* was classified as medium risk in a study conducted using FISK in Southern Finland (Puntilla et al., 2013). Fringebarbel sturgeon *Acipenser nudiventris* was considered invasive for both China and Korean coasts (Seo and Lee, 2009). Brown-marbled grouper *Epinephelus fuscoguttatus* is the species with the lowest score among the species classified as medium risk. There are reports of Ciguatera poisoning belonging to the species (Froese and Pauly, 2019).

The majority of the species that are classified as low-risk in this study are of tropical origin with the exception of deep water species (*Prognathodes guyotensis*), temperate species (*Chelmonops truncates*) and subtropical species (*P. aya, P. brasiliensis, Chelmonops curiosus, Prognathodes falcifer, Hemitaurichthys multispinosus*). Many of the tropical species are also used in the aquarium industry (Table 2).

As a conclusion, the results of the study, which was carried out with 57 species for South Korea marine habitat, showed that the risk assessments were successfully carried out using AS-ISK program. As Risk Assessment (RA) areas are dynamically in a constant state of change, a risk analysis should be carried out when a possible new species is likely to be introduced or new information is obtained about the species that have been previously evaluated. Also, although it has been studied in many different categories, it is useful to evaluate all species belonging to different environments (freshwater, brackish and marine) and groups (e.g. Paganelli et al., 2018). It is an important necessity to discuss and resolve the results presented in this study on whether or not the non-native species are potentially riskier in a broader perspective, including marine fishery biologists, ministry managers, and private sector officials. Otherwise, the usability and usefulness of the results will remain very limited. In order to utilize the results obtained in a beneficial manner, it is necessary to prevent the species, which are identified as high risk from introducing the risk assessment area, to take necessary measures and to start monitoring studies.

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