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Risk screening of non-native suckermouth armoured catfishes *Pterygoplichthys* spp. in the River Dinh (Vietnam) using two related decision-support tools

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Abstract

The invasion risk of non-native suckermouth catfishes *Pterygoplichthys* spp. in the River Dinh (Vietnam) was evaluated using two related decision-support tools, namely the Fish Invasiveness Screening Kit (FISK) and the Aquatic Species Invasiveness Screening Kit (AS-ISK). The results of screenings obtained independently by three assessors using both toolkits were evaluated for consistency, and compared with a screening study previously obtained for Vietnam as a wide risk assessment area. Both FISK and AS-ISK based screenings were shown to provide adequate and potentially important outcomes in terms of risk of invasiveness and were consistent amongst assessors and between toolkits. The invasion risk of *Pterygoplichthys* in the River Ding was found to be high and the traits of these fishes that influence their success of becoming established were considered. Some aspects in the use of FISK and AS-ISK as decision-support tools as part of the overall risk analysis of species' invasions for large risk assessment areas are discussed.

Keywords: biological invasions, *Pterygoplichthys* spp., Vietnam, risk analysis, screening tools, Fish Invasiveness Screening Kit (FISK), Aquatic Species Invasiveness Screening Kit (AS-ISK)

Introduction

The South American suckermouth armoured catfishes *Pterygoplichthys* spp. (Loricariidae) have spread widely around the world as a result of the ornamental fish industry (Nico et al., 2012; Wei et al., 2017; Saba et al., 2020) and have recently been identified as posing a "very high risk" of being or becoming invasive (Vilizzi et al., 2021). These fishes have successfully invaded freshwaters in the Americas (da Silva, 2019), Africa (Marr et al., 2017), Asia (Suresh et al., 2019) and the Pacific Islands (Saba et al., 2020).

In addition to invading tropical waters, *Pterygoplichthys* spp. have become established in some subtropical regions including northern Florida, USA (Nico et al., 2012) and Guangdong province in China (Wei et al., 2017). They have been introduced further into temperate regions particularly Italy (Piazzini et al., 2010), Poland (Keszka, Panicz, and Tanski, 2008) and Serbia (Simonović, Nikolić, and Grujić, 2010). For a summary of their expansion across the globe see Orfinger and Goodding (2018). Additionally, thermal refuges have been shown to facilitate local establishment of alien fishes (Zworykin and Pashkov, 2010; Nico et al., 2012; Tuckett et al., 2021). Taking into account global climate change, the suckermouth catfishes are likely to be found in other water bodies of southern Europe in the coming future.

In Vietnam, armoured catfishes were first discovered in the early 21st century, both in the south (Serov, 2004) and in the north (Levin, Phuong, and Pavlov, 2008)

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Ethics statement: As far as this study deals only with decision support tools FISK and AS-ISK and no living animals were used or caught for this particular study, there was no need to obtain an IACUC or any other kind of ethical committee approval.

Competing interests: The authors have declared that no competing interests exist.

of the country. The first established *Pterygoplichthys* population was recorded from Central Vietnam in 2013 (Zworykin and Budaev, 2013). To date, multiple findings of these fishes have been reported in the country (Stolbunov, Dien, and Armbruster, 2020), though suckermouth catfishes are known to have successfully established only in South and Central Vietnam where the climate is similar to the species' natural habitat. Although findings of *Pterygoplichthys* spp. are also reported in northern Vietnam (Vân et al., 2018), where a subtropical climate prevails, there are no reliably confirmed established populations there.

The wide and rapid distribution of non-native species requires methods to evaluate the risks associated with their invasion of new habitats. Risk is typically defined as the combination of the probability and consequences of adverse events (Aven, 2012; Hopkin, 2021). Invasion risk therefore includes not only the likelihood of establishment of a population of a non-native species, but also of a range of potential impacts (Britton, Copp, Brazier, and Davies, 2011). Environmental risk analysis consists of several components of which the first two are hazard identification (risk screening) and comprehensive risk assessment (Hill et al., 2020). As full-scale studies of biological invasions are costly and time-consuming, decision-support tools that would enable rapid preliminary risk screening are useful. The use of such tools technically belongs to the category of "heuristic methods", which provide sufficient results to solve the problem but are not guaranteed to be completely accurate. In this regard, several teams have been developing such risk screening/assessment toolkits (González-Moreno et al., 2019; Marcot et al., 2019; de Camargo, Cunico, and Gomes, 2022; Vilizzi, Hill, Piria, and Copp, 2022).

One of the most widely used risk screening toolkits for freshwater fish is the Fish Invasiveness Screening Kit (FISK) (Lawson et al., 2013; Vilizzi et al., 2019), and its successor — the Aquatic Species Invasiveness Screening Kit (AS-ISK) (Copp et al., 2021; Vilizzi et al., 2021), which is suitable for all aquatic species. Both FISK and AS-ISK are based on the architecture and question template of the Weed Risk Assessment (WRA) tool (Pheloung, Williams, and Halloy, 1999). All known quantitative risk screenings of the potential invasiveness of *Pterygoplichthys* spp. have been carried out using both FISK (Simonović, Nikolić, and Grujić, 2010; Marr et al., 2017; da Silva, 2019; Saba et al., 2020) and AS-ISK (Tarkan et al., 2017; Suresh et al., 2019). To date, the only application of AS-ISK in Vietnam including a screening for *P. pardalis* was recently carried out by Ruykys et al. (Ruykys et al., 2021).

Two main reasons can be outlined for carrying out the present study:

1. Ruykys et al. (Ruykys et al., 2021) did not conduct a risk screening for a specific biotope and case of invasion, but for the whole of Vietnam as a large risk assessment area. However, due to the extensive length of Vietnam from north to south (about 1,750 km) with noticeable differences in altitude and other geographical features, climatic and environmental conditions tend to differ for each region (Gupta, 2005; Sterling, Hurley, and Minh, 2006). The country's territory belongs to nine different freshwater ecoregions (Fig. 1A; Zworykin, 2014; Abell et al., 2008), and seven distinct types of climates are present (Fig. 1B; Beck et al., 2018). As a result, risk screenings can vary from habitat to habitat, and the probability of *Pterygoplichthys* spp. establishment is likely to vary from biotope to biotope. This poses the question of whether the risk of suckermouth catfish establishment is really high for the whole of Vietnam, including its northern regions.

2. Despite the development of AS-ISK, FISK is still currently used (Saba et al., 2020; Pandakov et al., 2021; Kim and An, 2021; de Camargo, Cunico, and Gomes, 2022; Medellin-Castillo et al., 2022), and some authors continue to refer to it as a tool that is still valid and can be employed in the future (Lawson and Hill, 2021). Moreover, it is expected that new versions of the WRA-type decision-support tools will be released. The question is, therefore, how the risk ranks obtained with related tools (including FISK and AS-ISK) compare to each other. In this regard, even for the same species screened for the same risk assessment area and by the same assessors, different results were obtained. In particular, AS-ISK was used to re-assess invasive fish species in Turkey previously screened using FISK. Of the 35 species, the ranking of five species dropped and the ranking of one species increased (Tarkan et al., 2017). This raises the question of whether risk ranks from the two toolkits are consistent.

Given the above, the aims of the present study were to: (i) analyse a specific case of invasion of non-native armoured catfishes *Pterygoplichthys* spp. in the River Dinh basin in Vietnam, and (ii) evaluate the FISK and AS-ISK by comparing the obtained estimates amongst the assessors and between the toolkits, and relating them with the overall screening previously obtained for Vietnam as a large risk assessment area.

Materials and methods

The present study focused on a population of non-native catfishes *Pterygoplichthys* spp. established in the River Dinh basin (Vietnam, Khánh Hòa Province: 12°29.57 N; 109°07.92 E; Fig. 1C), that has been monitored since 2010 (Zworykin and Budaev, 2013). It is unknown how long ago the population became established in the basin, but by 2010 it was already abundant. Risk screenings relied on personal and Local Ecological Knowledge (LEK) data (Hind, 2015), which were collected through semi-structured interviews with local fishers (Berkström, Papadopoulos, Jiddawi, and Nordlund, 2019), mainly from Ninh Hiệp village.

The taxonomic status of invasive suckermouth catfishes is unclear. The *Pterygoplichthys multiradiatus* group

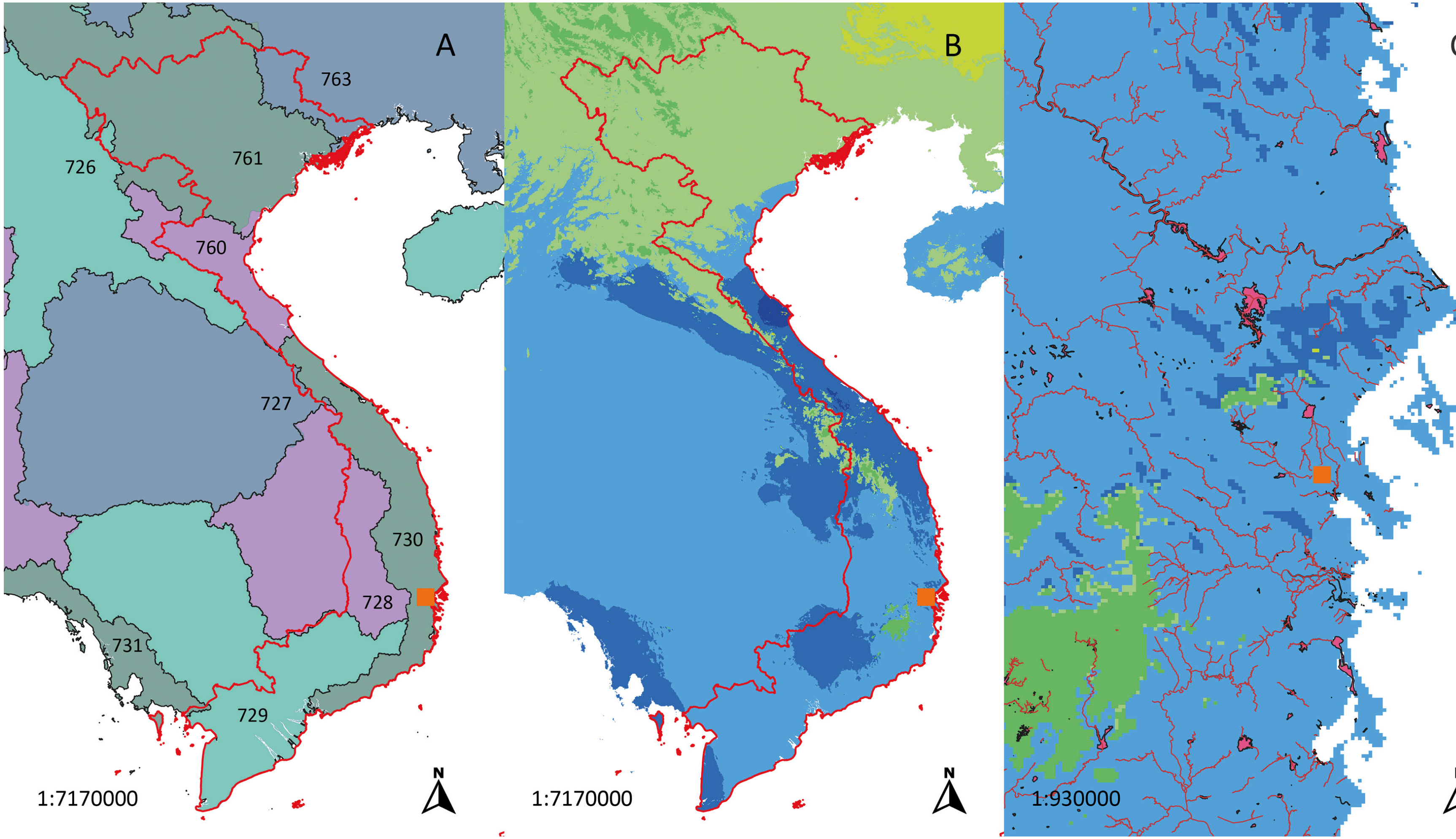

Fig. 1. Maps of freshwater ecoregions and climate types showing the location of the studied *Pterygoplichthys* spp. population. The data were visualised and analysed using QGIS software (QGIS v3.26.3 was downloaded from https://www.qgis.org/en/site/). Shapefiles (layers) were downloaded from HDX (https://data.humdata.org/), FEOW (https://www.feow.org/), GloH2O (http://www.gloh2o.org/koppen/) and Geofabrik (http://www.geofabrik.de/). Red line — the state border of Vietnam.

■ — *Pterygoplichthys* spp. population in the River Dinh.

A — Freshwater ecoregions. IDs *sensu* Abell et al. (2008). ID 726 — Lower Lancang (Mekong), ID 727 — Khorat Plateau (Mekong), ID 728 — Kratie — Stung Treng (Mekong), ID 729 — Mekong Delta, ID 730 — Southern Annam, ID 731 — Eastern Gulf of Thailand Drainages, ID 760 — Northern Annam, ID 761 — Song Hong, ID 763 — Xi Yiang.

B — Köppen-Geiger climate classification map of Vietnam (some climate types are not visible on a map at this scale).

■ — Tropical, Rainforest (*Af*), ■ — Tropical, Monsoon (*Am*), ■ — Tropical, Savanna, Dry winter (*Aw*), ■ — Arid, Steppe, Hot (*Bsh*), ■ — Temperate, Dry winter, Hot summer (*Cwa*), ■ — Temperate, Dry winter, Warm summer (*Cwb*), ■ — Temperate, No dry season, Hot summer (*Cfa*).

C — The established population of *Pterygoplichthys* spp. on the climate map. Pink spots and lines — waterbodies.

Fig. 2. Variations in ventral colour patterns of *Pterygoplichthys* spp. in the River Dinh. Photo by Dmitry Zworykin.

consists of four species: *P. multiradiatus* (Hancock 1828), *P. pardalis* (Castelnau 1855), *P. ambrosettii* (Holmberg 1893) (syn. *P. anisitsi* sensu Ferraris, 2007) and *P. disjunctivus* (Weber 1991). Members of this species complex are currently spreading throughout the world. Apart from their range, these species differ only in their colour patterns (Armbruster and Page, 2006). However, there is high variability in colouration, and some variants do not correspond to any of the species. This can be explained either by interspecific hybridisation or by the assumption that at least some members of the *P. multiradiatus* group are not actually valid species (Zworykin and Budaev, 2013; Wei et al., 2017). However, neither suggestion is currently conclusively confirmed, and therefore it is not possible to determine the species' identity in this group, and especially so outside their natural range. Accordingly, like several other authors in recent years (e. g. Wei et al., 2017; Stolbunov, Dien, and Armbruster, 2020; Seshagiri et al., 2021), in the present study the "open nomenclature" *Pterygoplichthys* spp. is used to refer to these fishes (Fig. 2).

The FISK v2.03 and AS-ISK v2.2. toolkits were downloaded from www.cefas.co.uk/nns/tools/. Currently, FISK is no longer available for download and is not supported, but continues to be used (see Introduction). The screening protocol of both toolkits consists of 49 questions grouped into sections and categories within sections (Vilizzi et al., 2019; Copp et al., 2021), that comprise the Basic Risk Assessment (BRA). Each question can be answered with varying degrees of confidence (certainty) and a justification based on literature resources must be provided by the assessor. Unlike the FISK, the AS-ISK includes an additional six questions that comprise the Climate Change Assessment (CCA).

Screenings were conducted independently by three researchers who have been studying the *Pterygoplichthys* spp. population in the River Dinh for several years. Each assessor carried out screenings with both toolkits, although the CCA questions in AS-ISK were not answered as a comparison would not have been possible with FISK. The assessors did not use the import option from FISK to AS-ISK but carried out a new screening from scratch under AS-ISK. As a result, six assessor × toolkit risk score combinations sets of numbers were obtained. To risk-rank the score outcomes for *Pterygoplichthys* spp. in the River Dinh (the risk assessment area in this study), for FISK the generalised threshold of 15.5 was used (Vilizzi et al., 2019) and for AS-ISK both the generalised threshold of 14.7 for freshwater fishes (Vilizzi et al., 2021) and the threshold of 6.5 for Vietnam (Ruykys et al., 2021) were used.

These estimates were analysed for compliance with the data accumulated over ten years of monitoring of the established population of *Pterygoplichthys* spp. The distribution of the total score across the different variables and categories was then considered. Correlation methods were used to analyse the consistency of the scores amongst the assessors within each version of the toolkit, and of the same assessor in the two versions of the toolkit. Spearman's rank correlation (Rρ), Goodman and Kruskal's gamma (Rγ) and Kendall's coefficient of concordance (W) were used.

Results

Both personal data and interviews with local fishers indicated that the *Pterygoplichthys* spp. population in the River Dinh has not changed significantly over the last ten years (unpublished annual reports of the Coastal Branch of Vietnam-Russian Tropical Research and Technological Centre, 2010–2017), and only minor fluctuations in abundance have been observed. In particular, an increase in abundance was noted in late 2016 and early 2017 following severe flooding in the area.

The mean total score and breakdown across sections and categories as well as sectors affected for the three assessors using both toolkits are provided in Table 1. Both tools estimated the level of invasiveness of *Pterygoplichthys* spp. in the risk assessment area as "high" when compared to the generalised threshold for FISK and AS-ISK and the one for Vietnam. Despite overall consistency in the results, AS-ISK resulted in an outcome score higher than FISK. Although the partial scores for the Biogeography/Historical section were almost identical, the difference was almost twice as much in the Biology/Ecology section. Specifically, the importance of undesirable traits related to features such as ability to disrupt established food chains was found to be higher in AS-ISK relative to FISK. AS-ISK also emphasised Tolerance attributes, which agrees with data concerning the species' resistance to predation, euryhalinity and ability to live out of water for a long time. Finally, use of *Pterygoplichthys* spp. as an ornamental fish also contributed negatively by increasing the score especially in AS-ISK.

Climate similarity contributed to a limited extent to the overall score, which is understandable as the climate at the introduction site, although similar to the natural climate for these fishes, is not identical (*Aw* vs *Af* under the Köppen-Geiger climate classification). This was similar to Feeding guild/Resource exploitation, likely due to the fact that *Pterygoplichthys* spp. occupy a specific food niche in the River Dinh associated with a diet predominantly based on detritus. A low contribution to the overall score was finally made by Reproduction and Dispersal mechanisms.

Table 2. Consistency in screenings by different assessors in the two toolkits

	Rρ		Rγ		W
FISK	min	0.96, p < 0.001	min	0.89, p < 0.001	0.96, p = 0.005
	max	0.97, p < 0.001	max	0.96, p < 0.001	
AS-ISK	min	0.94, p < 0.001	min	0.92, p < 0.001	0.92, p = 0.007
	max	0.97, p < 0.001	max	1.00, p < 0.001	
FISK vs AS-ISK	min	0.89, p < 0.001	min	0.80, p < 0.001	—
	max	0.98, p < 0.001	max	1.00, p < 0.001	

Results of the consistency analysis of the score outcomes by the different assessors and using the different toolkits are presented in Table 2. There was a high level

Table 1. FISK and AS-ISK screening outcomes for *Pterygoplichthys* spp. in the River Dinh (Vietnam)

	FISK			AS-ISK		
	Section/Category	Mean	SD	Section/Category	Mean	SD
A	Biogeography/Historical	15.33	4.04	Biogeography/Historical	15.83	3.33
1	Domestication/Cultivation	3.33	0.58	Domestication/Cultivation	4.00	0.00
2	Climate and distribution	2.00	0.00	Climate, distribution and introduction risk	2.00	0.00
3	Invasive elsewhere	10.00	3.46	Invasive elsewhere	9.83	3.33
B	Biology/Ecology	12.00	1.00	Biology/Ecology	22.33	1.53
4	Undesirable traits	6.67	1.15	Undesirable (or persistence) traits	9.67	1.15
5	Feeding guild	0.00	0.00	Resource exploitation	1.33	1.15
6	Reproduction	0.67	0.58	Reproduction	2.00	0.00
7	Dispersal mechanisms	1.00	1.00	Dispersal mechanisms	2.33	1.53
8	Persistence attributes	3.67	0.58	Tolerance attributes	7.00	2.00
Score		27.33	4.16	Score	38.17	2.93
Sectors affected						
Aquacultural		16.67	2.08	Commercial	13.00	1.00
Environmental		26.67	1.53	Environmental	4.00	2.00
Nuisance		1.67	1.15	Species or population nuisance traits	25.83	3.75

of correlation between the independent assessments, as indicated by the Spearman correlation coefficient that did not fall below 0.94, and the Goodman and Kruskal's gamma showed similar results. Based on the Kendall's coefficient of concordance, there was a high level of consistency between the screenings in general. Finally, a comparison of the scores obtained by each of the assessors revealed a high level of correlation between the values obtained with the two toolkits.

Discussion

The study of non-native species in Vietnam is at its onset and recorded populations of non-native fishes are more often than not unstudied. Under these circumstances, the availability of decision-support tools in risk analysis is especially important. A variety of risk screening and assessment toolkits for identifying potentially invasive non-native species has revealed the need to verify both the adequacy and consistency of the related outcomes. In fact, some comparative studies have revealed mismatches in both outcomes and assessor's certainty/confidence, but also an overall low level of consistency (e.g. Almeida et al., 2013; González-Moreno et al., 2019). In addition, the debate between developers about alternative decision-support tools has intensified in recent years (Marcot et al., 2019; Hill et al., 2020). The present results have demonstrated the adequacy and consistency of FISK and AS-ISK based screenings, and the assessor's expertise appears to be a critical factor, as pointed out by several authors (e.g. González-Moreno et al., 2019; Vilizzi, Hill, Piria, and Copp, 2022).

WRA-type decision-support tools, including FISK and AS-ISK, can be used at different scales in terms of risk assessment area. In this regard, the definition of a large risk assessment area may be often challenging, as the larger and more diverse the area, the more difficult it is to achieve accurate predictions. Regardless, the risk assessment area is quite often defined at the country level, possibly because of the need to communicate the screening outcomes to decision-makers for the development/improvement of national policy and legislation. However, political borders often have little correlation with ecological and climatic conditions, and in this respect meta-analyses have shown that calibration at this level is possible (Vilizzi et al., 2019, 2022).

The present screening outcomes indicated a high risk associated with the establishment of *Pterygoplichthys* spp. in the River Dinh basin of Vietnam. In previous studies, the invasion risk of suckermouth catfish has been ranked as either medium or high (Marr et al., 2017; Tarkan et al., 2017; Wei et al., 2017; da Silva, 2019; Suresh et al., 2019; Saba et al., 2020). The AS-ISK score for the River Dinh population was almost identical to the one for *P. pardalis* for the whole of Vietnam (Ruykys et al., 2021; 38.17 vs 38.00). Ruykys et al. (Ruykys et al., 2021) believed that the climate of Vietnam is in line with the climate of *Pterygoplichthys* in their native range, and estimated their risk of invasiveness as high. In fact, numerous catches of armoured catfishes have been recorded in Vietnam, but only a few of these populations can be considered established. The species' natural range belongs predominantly to the tropical rainforest climate (*Af*) under the Köppen-Geiger classification. This resembles that of South Vietnam, which for the most part is tropical savanna (*Aw*) and where *Pterygoplichthys* spp. have become established. Conversely, the *Af* climate is quite different from the humid subtropical climate (*Cwa*) that characterises the Red River basin in Northern Vietnam, where catfishes have been repeatedly recorded but not confirmed to become established there.

Although the AS-ISK score was noticeably higher than the one obtained with FISK (38.17 vs 27.33), direct comparison between these values is not correct. This is because these toolkits involve different calculation algorithms and the results cannot be regarded as truly homogeneous data. Further, the score by itself has limited informative value as, ideally, each risk assessment area (as per the River Dinh) subject to biological invasions should be screened for a wide range of fish to allow risk assessment area-specific calibration with resulting identification of thresholds for the species' risk-ranking (Vilizzi et al., 2021). In this respect, the first calibration study for Vietnam as a whole by Ruykys et al. (2021), albeit important, should be regarded as preliminary. The reason for this is that the set of non-native aquatic species screened by the authors was of a relatively small size (only 14 species of fish out of 30 species of aquatic animals screened in total), whereas the number of non-native aquatic animal species in Vietnam is likely to exceed 170 (An et al., 2013).

Damage to the Commercial (Aquacultural) Sector was quantified by FISK and AS-ISK to be roughly the same, i.e., quite considerable. Indeed, *Pterygoplichthys* spp. can cause damage to fishing nets and gear with their spiny fins, which in some cases has been shown to be substantial (Seshagiri et al., 2021). However, the local fishers interviewed in the present study did not believe that this harm would be considerable. Moreover, catfish are bought by aquarium fish stores, so they represent an additional source of income for local people. The damage to the other two affected Sectors was evaluated differently. This is because the AS-ISK focuses more on Species or population nuisance, whereas FISK considers damage to the Environmental sector more important. According to personal observations, armoured catfish in many (but not all) habitats exert little impact on native fish, as they are neither predators nor competitors for resources. However, they often provoke coastal erosion by digging long and ramified spawning burrows in coastal slopes (Nico et al., 2012). Thus, in this respect, the use of FISK may be more accurate than AS-ISK.

The low contribution of variables related to Reproduction and Dispersal mechanisms (Table 1) is particularly interesting in the context of the current debate on the effect of reproductive strategy on invasion success. Clearly, there are species with very different reproductive modes amongst successful invaders, but both model predictions (Moyle and Marchetti, 2006; Lawson and Hill, 2021) and field data (Grabowska and Przybylski, 2015; Dashinov and Uzunova, 2021) indicate the potential benefit of certain reproductive strategies for non-native species' establishment in new habitats. In the case of *Pterygoplichthys* spp., one explanation for their successful worldwide spread may also be due to their reproductive traits, as suggested by some authors (da Silva, 2019). However, no clear confirmation of this hypothesis has yet been obtained, and the present FISK and AS-ISK screenings appear to contradict this hypothesis. It has also been shown that one of the key factors in the successful colonisation of new habitats by fish is not following a particular type of strategy, but rather the high plasticity of any strategy (Top et al., 2018). This appears to be true also for *Pterygoplichthys*, as indicated by some studies (Gibbs, Watson, Johnson-Sapp, and Lind, 2017; Wei et al., 2017).

In conclusion, the results of this study suggest that FISK and AS-ISK based screenings of the risk of invasiveness of non-native species provide adequate and potentially important outcomes, which appear to be consistent amongst experts and between toolkits. However, despite the continued use of FISK, this toolkit not only has been "deprecated" following release of AS-ISK but also a computational error present in both toolkits (and originally in the WRA) has recently been fixed in AS-ISK v2.3.3 (currently available at www.cefas.co.uk/nns/tools) but not in FISK, which is no longer supported. For this reason, FISK should no longer be used in any further risk screening studies as both redundant and ill advised.

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