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Risk screening of non-native freshwater fishes at the frontier between Asia and Europe: first application in Turkey of the fish invasiveness screening kit

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Summary

The aim of the present study was to assess the invasive potential of introduced non-native and translocated fishes in Turkey (Anatolia and Thrace) by applying the Fish Invasiveness Screening Kit (FISK), a risk identification tool for freshwater fishes. From independent evaluations by two assessors of 35 species, calibration of FISK for Turkey identified a threshold score of 23, which reliably distinguished between potentially invasive (high risk) and potentially non-invasive (medium to low risk) fishes for Anatolia (Asia) and Thrace (Europe). No species was categorized as 'low risk', 18 species were categorized as 'medium risk' and 17 as 'high risk' (two being 'moderately high risk', nine 'high risk', and six 'very high risk'). The highest scoring species was gibel carp *Carassius gibelio*, whereas the lowest scoring species was Caucasian dwarf goby *Knipowitschia caucasica*, a translocated species. Assessor certainty in their responses averaged overall between 'mostly uncertain' and 'mostly certain', with red piranha *Pygocentrus nattereri* and topmouth gudgeon *Pseudorasbora parva* achieving the lowest and highest certainty values, respectively, and with overall significant differences in certainty between assessors. The results of the present study indicate that FISK is a useful and viable tool for identifying potentially invasive non-native fishes in Turkey, a country characterized by natural biogeographical frontiers.

Introduction

With some 310 species, at least 25% of which are endemic, Turkey possesses the largest number of freshwater fish species of any other region in the Mediterranean Basin (Froese and Pauly, 2013). Situated at the junction of three large biogeographical regions (Holoarctic, Sinoindian and African) and acting as a refugium during the last glacial period (Blondel and Aronson, 1999), Turkey is an extremely diverse region in terms of fauna and zoogeography (Bogutskaya, 1992). Turkey is divided by the two sea straits of Istanbul and Dardanelles into two different zoogeographical areas, the provinces of Thrace and Anatolia, which also represent part of the frontier between Europe and Asia, respectively. Because of the presence of mountain ridges, which represent an important barrier for freshwater fish dispersion (Kosswig, 1955), the Anatolian peninsula is characterized by a high level of speciation as well as presence of endemic species. The bridging location of Turkey across two continents makes the country an important recipient region for species' introductions and translocations. In fact, despite the presence of salt-water barriers, non-native species continue nonetheless to be introduced to Anatolia from the European part of the country.

Regardless of the presence in Turkey of two different zoogeographical regions, the risk assessment area for non-native species is generally defined at the country (i.e. political) level (see summary in Copp, 2013). Thus, 33 non-native freshwater fish species in total are currently recognized, including species translocated within the country (terminology throughout after Copp et al., 2005a). The number of introduced fishes continues to increase as a result of climate change and human intervention, the latter including degradation of rivers and streams due to water abstraction, gravel extraction, eutrophication, emission of various waterborne pollutants (i.e. agricultural, municipal, industrial, aquacultural), as well as construction of water retention structures (Fricke et al., 2007). The biological diversity of freshwater fishes in Turkey is further threatened by overfishing and the introduction of non-native organisms (Elton, 2000). For example, the extirpation of two endemic fish species in lakes Eğirdir and Beyşehir has been attributed to the introduction of the non-native piscivore pikeperch *Sander lucioperca* (Küçük, 2012) and declines in native fishes in the Ömerli Reservoir can be explained in part by a gibel carp *Carassius gibelio* invasion of the waterbody (Tarkan et al., 2012a).

Fish introductions to Turkey have a long history, beginning with the domesticated form of common carp *Cyprinus carpio* at least as early as the Roman period and with the wild form formerly restricted to the northernmost areas (Balon, 1995; Vilizzi, 2012). Consumed by local people as a very popular fish species, *Cyprinus carpio* now represents the bulk of aquaculture production in Turkey, with its spread facilitated by stocking programmes (Harlıoğlu, 2011). Another early introduction throughout Turkey was that of the eastern mosquitofish *Gambusia holbrooki* during the 1930s for malaria control (Geldiay and Balık, 1988).

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Subsequent introductions took place during the mid-20th century, and besides *Cyprinus carpio* the most common non-native fishes in Turkey currently are gibel carp *Carassius gibelio*, top mouth gudgeon *Pseudorasbora parva* and pumpkinseed *Lepomis gibbosus*, all of which were introduced unintentionally as contaminants in *Cyprinus carpio* consignments for stocking (Ekmekçi and Kırankaya, 2006; Aydın et al., 2011; Önsoy et al., 2011). In addition to aquaculture and fisheries enhancement practices, the other known pathway of introduction for some other species (e.g. redbelly tilapia *Coptodon zilli*, Nile tilapia *Oreochromis niloticus*, brook trout *Salvelinus fontinalis*) has been from government and university research facilities (Dikel, 1995; Başçınar, 2001). Finally, the most recent introduction has been that of the Asian stinging catfish *Heteropneustes fossilis*, which entered Turkey in 2011 from Syria via the River Tigris (Ünlü et al., 2011).

The success of non-native fish introductions has varied between the European and Asian parts of Turkey, with eight of the non-native species successfully establishing themselves in Thrace, and 11 non-natives establishing self-sustaining populations in Anatolia (A. S. Tarkan, S. M. Marr & F. G. Ekmekçi, unpubl. data). Furthermore, an additional 12 species were translocated within Turkey of which 11 were legal introductions by the Turkish government (e.g. pike-perch *Sander lucioperca*, tench *Tinca tinca,* European catfish *Silurus glanis,* Eurasian perch *Perca fluviatilis*) and one illegal introduction (sandsmelt *Atherina boyeri*). Despite the fact that all of these translocations resulted in self-sustaining populations, only two of these species have been able to maintain abundant and healthy populations (*Tinca tinca* and African catfish *Clarias gariepinus*) – pollution and overfishing appear to explain the failure of the other introductions (A. S. Tarkan, S. M. Marr, & F. G. Ekmekçi, unpubl. data).

Studies of non-native fish impacts in Turkey remain scarce (but see Küçük, 2012; Tarkan et al., 2012a,b), and risk analysis of non-native species is virtually non-existent. To provide the first evaluation of risks posed by non-native freshwater fishes in Turkey, the aim of the present study was to undertake a risk identification assessment of existing and potential non-native and translocated species using the Fish Invasiveness Screening Kit (FISK) to determine which species – current and potential future – are likely to pose a risk of being invasive in Turkey. This tool was adapted from the Australian Weed Risk Assessment (Pheloung et al., 1999) for use with freshwater fishes (Copp et al., 2005b, 2009) and subsequently improved for wider climatic applicability (Lawson et al., 2013). FISK has been applied in all or part of at least 15 countries across five continents (summarized in Copp, 2013), including Belarus (Mastitsky et al., 2010), Japan (Onikura et al., 2012), Brazil (Troca and Vieira, 2012), Belgium (Verbrugge et al., 2012), Australia (Vilizzi and Copp, 2013), Finland (Puntila et al., 2013), the USA (Lawson et al., 2013), Mexico (R. Mendoza, pers. comm.), England & Wales (Copp et al., 2009) as well as five nearby Mediterranean countries of the Balkans region (Simonović et al., 2013) and the Iberian peninsula (Almeida et al., 2013). The intention of the present risk identification procedure in Turkey is to inform local environmental managers on the potential invasiveness of existing and potential future non-native fishes.

Materials and methods

In total, 35 freshwater fish species (Table 1) were assessed with FISK v2 (Lawson et al., 2013; decision support tool available at: www.cefas.defra.gov.uk/4200.aspx) for Turkey as the risk assessment area, with the two parts of the country, Anatolia (Asia) and Thrace (Europe) distinguished as sub-areas. Selection of species was based on four criteria: (i) translocated native species, i.e. species native to one or more drainage basins in Turkey that have been frequently translocated across watersheds into drainage basins outside their native range; (ii) non-native species already present in Turkey; (iii) non-native species not yet present in Turkey but established in nearby donor areas to the north (Greece and Bulgaria: cf. Economidis et al., 2000) and south (Iran and Syria: Coad and Hussain, 2007; Coad, 2010; Ünlü et al., 2011); and (iv) non-native species important for the aquarium trade. Of the 35 fish species selected, five (14.3%) corresponded to criterion (i), 21 (60.0%) to criterion (ii), four (11.4%) to criterion (iii) and five (14.3%) to criterion (iv).

Receiver Operating Characteristic (ROC) analysis (Bewick et al., 2004) was used to assess the predictive ability of FISK to discriminate between species posing a 'high risk' (invasive) and those posing a 'medium-to-low risk' of being invasive (non-invasive). Species were categorized *a priori* in terms of their perceived invasiveness (invasive or non-invasive) and protection status (conservation concern category: Not evaluated, Least concern, Vulnerable, Near threatened) based on information available from the Invasive Species Specialist Group database (http://www.issg.org/) and from FishBase (http://www.fishbase.org/home.htm). Statistically, a ROC curve is a graph of sensitivity vs 1 – specificity (or alternatively, sensitivity vs specificity), where in the present context sensitivity and specificity will be the proportion of invasive and non-invasive fish species, respectively, that are correctly identified by the FISK tool as such. 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 (the ROC 'curve' consists of two straight lines, one vertical from 0.0 to 0.1 and the other horizontal from 0.1 to 1.1), then the test is 100% accurate because both sensitivity and specificity are 1.0 and there are neither false positives (non-invasive species categorized as invasive) nor false negatives (invasive species categorized as non-invasive). Conversely, if the AUC is equal to 0.5 (the ROC 'curve' being a diagonal line from 0.0 to 1.1), then the test is 0% accurate because it cannot discriminate between true positives (actual invasive species) and true negatives (actual non-invasive species). Typically, the AUC will range between 0.5 and 1.0, and the closer the AUC to 1.0 the better the ability of FISK to differentiate between invasive and non-invasive species.

Two assessors (AST, FGE) knowledgeable in the fish fauna of Turkey carried out separate and independent assessments on all 35 species. Separate ROC curves were initially generated for the two assessors and differences between corresponding AUCs statistically tested (Mann–Whitney *U*-statistic,

Table 1
Freshwater fish species assessed for Turkey using Fish Invasiveness Screening Kit (FISK) v2 (Lawson et al., 2013). For each species, selection criterion, *a priori* invasiveness (http://www.issg.org/ and http://www.fishbase.org) and protection status (category initials http://www.iucnredlist.org/), along with summary statistics (SE = standard error) for corresponding FISK score, (risk) outcome and certainty factor (CF) (see text for computations)

Species name	Common name	Criterion	Invasiveness/ Protection status	Score				Out come	CF			
				Mean	Min	Max	SE		Mean	Min	Max	SE
Acipenser baerii	Siberian sturgeon	4	Non-invasive/Not evaluated	16.5	16.0	17.0	0.4	M	0.65	0.53	0.76	0.09
Ameiurus melas	Black bullhead	3	Invasive/Not evaluated	27.0	26.0	28.0	0.8	H	0.67	0.66	0.67	0.00
Atherina boyeri	Big-scale sand smelt	1	Non-invasive/Least concern	12.5	11.0	14.0	1.2	M	0.72	0.71	0.73	0.01
Carassius auratus	Goldfish	2	Invasive/Not evaluated	31.5	30.0	33.0	1.2	VH	0.74	0.70	0.79	0.04
Carassius gibelio	Gibel carp	2	Invasive/Not evaluated	38.0	38.0	38.0	0.0	VH	0.72	0.67	0.77	0.04
Clarias gariepinus	North African catfish	1	Invasive/Not evaluated	25.8	25.0	26.5	0.6	H	0.64	0.58	0.71	0.05
Coregonus lavaretus	European whitefish	2	Non-invasive/ Vulnerable	11.8	11.0	12.5	0.6	M	0.63	0.53	0.72	0.08
Ctenopharyngodon idella	Grass carp	2	Non-invasive/Not evaluated	29.0	26.0	32.0	2.4	H	0.70	0.65	0.76	0.04
Cyprinus carpio	Common carp	2	Invasive/ Vulnerable	32.0	30.0	34.0	1.6	VH	0.74	0.68	0.79	0.04
Gambusia affinis	Western mosquitofish	2	Invasive/Not evaluated	30.0	28.0	32.0	1.6	VH	0.71	0.63	0.79	0.06
Gambusia holbrooki	Eastern mosquitofish	2	Invasive/Not evaluated	31.0	30.0	32.0	0.8	VH	0.72	0.71	0.72	0.00
Hemiculter leucisculus	Sharpbelly	3	Invasive/Least concern	8.0	8.0	8.0	0.0	M	0.61	0.49	0.73	0.10
Heteropneustes fossilis	Asian stinging catfish	2	Non-invasive/Least concern	19.8	18.0	21.5	1.4	M	0.60	0.51	0.70	0.08
Hypophthalmichthys molitrix	Silver carp	2	Invasive/Near threatened	29.3	26.5	32.0	2.2	H	0.68	0.62	0.73	0.05
Ictalurus punctatus	Channel catfish	4	Invasive/Not evaluated	30.3	28.5	32.0	1.4	VH	0.68	0.64	0.72	0.03
Knipowitschia caucasica	Caucasian dwarf goby	1	Non-invasive/Least concern	4.5	3.0	6.0	1.2	M	0.67	0.62	0.72	0.04
Lepomis gibbosus	Pumpkinseed	2	Non-invasive/Not evaluated	26.3	25.5	27.0	0.6	H	0.73	0.71	0.76	0.02
Liza abu	Abu mullet	2	Non-invasive/Not evaluated	12.0	11.5	12.5	0.4	M	0.62	0.51	0.73	0.09
Liza haematocheila	So-iny mullet	3	Non-invasive/Not evaluated	27.5	25.0	30.0	2.0	H	0.68	0.63	0.72	0.04
Morone chrysops x Morone saxatilis	White/striped bass hybrid	2	Non-invasive/Least concern	14.3	13.5	15.0	0.6	M	0.63	0.53	0.72	0.08
Oncorhynchus mykiss	Rainbow trout	2	Invasive/Not evaluated	13.5	12.0	15.0	1.2	M	0.74	0.70	0.77	0.03
Oreochromis aureus	Blue tilapia	4	Invasive/Not evaluated	24.0	23.0	25.0	0.8	MH	0.61	0.49	0.73	0.10
Oreochromis mossambicus	Mozambique tilapia	4	Invasive/Near threatened	25.8	25.5	26.0	0.2	H	0.62	0.49	0.75	0.11
Oreochromis niloticus	Nile tilapia	2	Invasive/Not evaluated	25.0	25.0	25.0	0.0	H	0.67	0.65	0.69	0.02
Perccottus glenii	Chinese (Amur) sleeper	3	Non-invasive/ Vulnerable	16.0	14.0	18.0	1.6	M	0.63	0.58	0.68	0.04
Pseudorasbora parva	Topmouth gudgeon	2	Invasive/Not evaluated	29.0	27.0	31.0	1.6	H	0.78	0.78	0.79	0.00
Pterygoplichthys disjunctivus	Vermiculated sailfin catfish	2	Invasive/Not evaluated	24.8	24.0	25.5	0.6	MH	0.65	0.57	0.74	0.07
Pygocentrus nattereri	Red piranha	2	Non-invasive/Not evaluated	15.8	14.0	17.5	1.4	M	0.58	0.43	0.73	0.12
Salmo salar	Atlantic salmon	2	Non-invasive/Least concern	8.0	7.0	9.0	0.8	M	0.74	0.67	0.81	0.06
Salvelinus alpinus	Arctic char	2	Non-invasive/Least concern	6.0	4.0	8.0	1.6	M	0.60	0.46	0.74	0.11

Table 1
(Continued)

Species name	Common name	Criterion	Invasiveness/ Protection status	Score				Out come	CF			
				Mean	Min	Max	SE		Mean	Min	Max	SE
Salvelinus fontinalis	Brook trout	2	Invasive/Not evaluated	12.5	12.0	13.0	0.4	M	0.67	0.60	0.74	0.06
Sander lucioperca	Pikeperch	1	Invasive/Not evaluated	15.0	15.0	15.0	0.0	M	0.75	0.73	0.78	0.02
Tilapia rendalli	Redbreast tilapia	4	Invasive/Least concern	16.5	15.0	18.0	1.2	M	0.61	0.49	0.73	0.10
Tilapia zillii	Redbelly tilapia	2	Invasive/Not evaluated	21.3	17.5	25.0	3.1	M	0.71	0.70	0.71	0.00
Tinca tinca	Tench	1	Non-invasive/Least concern	22.0	21.0	23.0	0.8	M	0.67	0.64	0.71	0.03

Criteria: 1 = Translocated native species; 2 = Non-native species already present in Turkey; 3 = Non-native species currently not present in Turkey but established in nearby donor areas to the north and south; 4 = Non-native species important for aquarium trade. Outcome is based on a calibration threshold of 23 between medium and high risk species *sensu lato* and classified by [lower, upper] scores as: medium risk (M) = [1, 23[; moderately high risk (MH) =]23, 25[; high risk (H) =]25, 30[; very high risk (VH) =]30, 57]). Species names after http://www.fishbase.org.

$\alpha = 0.05$) (online applet StAR: http://protein.bio.puc.cl/star/home.php) (Vergara et al., 2008). Following between-curve comparison, a global ROC curve was computed on the mean scores from the two assessors. Based on the global ROC curve, the best FISK threshold (cut-off) value that maximizes the true positive rate (true invasive classified as invasive) and minimizes the false positive rate (true non-invasive classified as invasive) was determined using a combination of Youden's *J* statistic (Youden, 1950) and the point closest to the top-left part of the plot with perfect sensitivity or specificity. For the global ROC curve, a smoothed mean ROC curve was also generated and boot-strapped confidence intervals of specificities computed along the entire range of sensitivity points (0 to 1, at 0.1 intervals). Analyses were carried out with package pROC for R × 64 v2.13.0 (R Development Core Team, 2008) using 2000 bootstrap replicates.

As each response of FISK for a given species is allocated a certainty score (1 = very uncertain; 2 = mostly uncertain; 3 = mostly certain; 4 = very certain), a 'certainty factor' (CF) was computed as:

$\sum(CQ_i)/(4 \times 49)$ ($i = 1, \ldots, 49$)

where CQ_i is the certainty for question i, 4 is the maximum achievable value for certainty ('very certain') and 49 is the total number of questions comprising the FISK tool. The CF therefore ranges from a minimum of 0.25 (all 49 questions with certainty score equal to 1) to a maximum of 1 (all 49 questions with certainty score equal to 4).

For further assessment on consistency between assessors, an error (or confusion) matrix (Renken and Mumby, 2009) was computed and the corresponding coincidence rate determined for species categorization according to risk extent (medium, moderately high, high, very high). The CFs for the 35 species were also compared between assessors by a one-way permutational univariate analysis of variance (PERANOVA), using a Euclidean dissimilarity measure following normalisation and n = 9999 permutations of the raw data (PERMANOVA+ for PRIMER v6: Anderson et al., 2008). All statistical tests in the present study were evaluated at $\alpha = 0.05$.

Results

There were no statistically significant differences ($P = 0.289$) between AUCs for the two assessor-specific ROC curves (Fig. 1, top). This justified the computation of a global ROC curve based on the mean scores, which resulted in an AUC of 0.7800 (0.6255–0.9345 95% CI), hence well above 0.5 (Fig. 1, bottom). This indicated that FISK was able to discriminate reliably between 'invasive' and 'non-invasive' species for Turkey. Youden's *J* and closest point statistics provided the same best threshold of 23, which was therefore chosen as the calibration threshold of FISK risk outcomes for Turkey (Table 1) and thus to distinguish between 'medium risk' species (species with FISK scores within the interval]1, 23[) and 'high risk *sensu lato*' species (species with FISK scores within the interval]23, 57]) – the latter can be further categorized (as per Britton et al., 2010) into 'moderately high risk' (interval]23, 25[), 'high risk' (interval]25, 30[), and 'very high risk' (interval]30, 57]), and with 'low risk' species having a FISK score within the interval [−15, 1[.

Based on the above threshold and corresponding intervals, none of the 35 species assessed was categorized as 'low risk' based on mean scores, whereas 18 (51.4%) were categorized as 'medium risk', and the other 17 (48.6%) as 'high risk' *sensu lato*, of which two (11.8%; 5.7% of total) as 'moderately high risk', nine (52.9%; 25.7% of total) as 'high risk', and six (35.3%; 17.1% of the total) as 'very high risk' (Table 1). The highest scoring species (very high risk) included *Carassius gibelio*, followed by *Cyprinus carpio*, goldfish *Carassius auratus*, *Gambusia holbrooki*, channel catfish *Ictalurus punctatus*, and western mosquitofish *Gambusia affinis*. The lowest scoring species (medium risk) was the Caucasian dwarf goby *Knipowitschia caucasica* (Table 1).

Among species classified *a priori* as invasive, but ranked here as medium risk, were those of 'least concern'; all other invasive species were ranked as high risk (Fig. 2). Amongst the latter, *Cyprinus carpio* was classified *a priori* as both 'vulnerable' (the original wild form) and invasive (the domesticated form), and received the second highest score (Table 1).

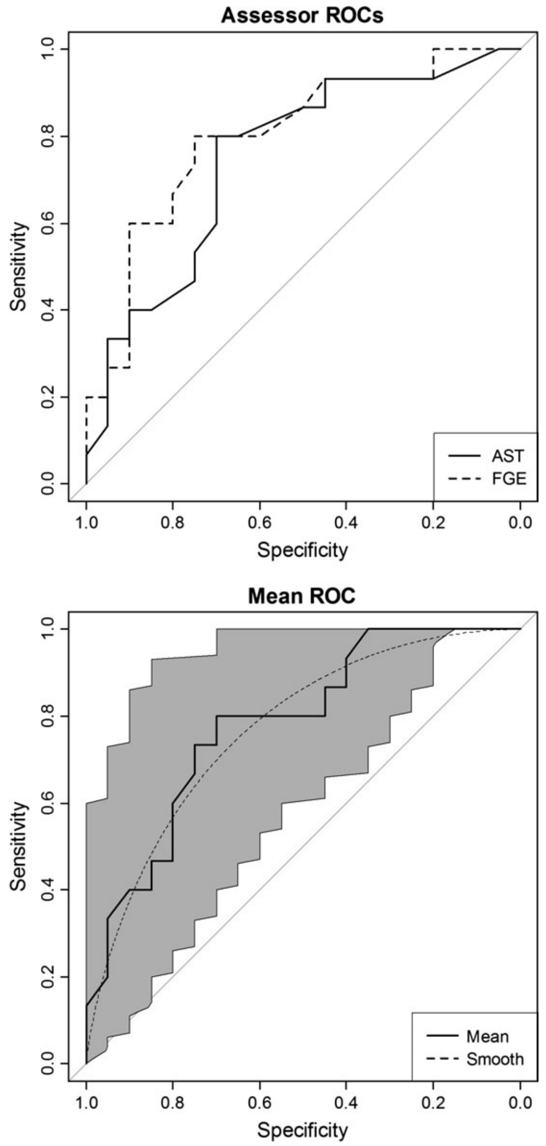

Fig. 1. Upper graph: Receiver operating characteristic (ROC) curves for two assessors (initials of the first two authors) on 35 fish species assessed by Fish Invasiveness Screening Kit (FISK) for Turkey. Lower graph: Mean ROC curve based on mean scores from the two assessors, with smoothing line and confidence intervals of specificities (see Table 1)

All non-invasive fishes were classified *a priori* as least concern, vulnerable or not evaluated, and all attracted scores within the medium risk category (Fig. 2).

Mean certainty in assessor responses for all species was 2.7 ± 0.2 SE (above the category 'mostly uncertain') and CF 0.67 ± 0.05 SE, and ranged from a minimum of 2.3 ± 0.5 SE (CF: 0.58 ± 0.12 SE) for red piranha *Pygocentrus nattereri* to a maximum of 3.1 ± 0.1 SE (CF: 0.78 ± 0.01 SE) for *Pseudorasbora parva* (Table 1). Finally, the coincidence rate between AST and FGE was 71%, as well as a significant difference in mean CF values between AST (0.73 ± 0.03) and FGE (0.62 ± 0.10) (permutational $F_{1,68} = 38.08$, P < 0.001).

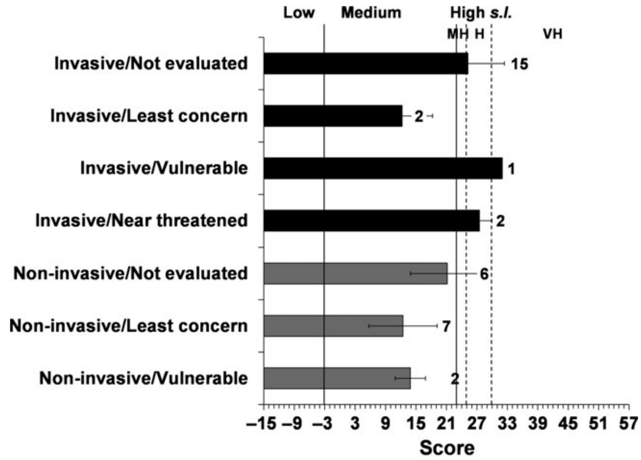

Fig. 2. Mean scores (±SE and n) for 35 fish species assessed by Fish Invasiveness Screening Kit (FISK) for Turkey, ranked according to *a priori* invasiveness and protection status (cf. Table 1). Thresholds: <1 (low risk) and ≥23 (high risk *sensu lato*), medium risk species in between. Risk categories and [lower, upper] scores: L = low risk [−15, 1[; M = medium risk]1, 23[; MH = moderately high risk]23, 25[; H = high risk]25, 30[; VH = very high risk]30, 57]

Discussion

Similar to FISK applications in the north (Simonović et al., 2013) and west (Almeida et al., 2013) of the Mediterranean region concerning non-indigenous and translocated freshwater fishes, assessments in the present study could discriminate reliably between invasive and non-invasive species in Turkey, irrespective of the assessor. The mean threshold value of 23 for Turkey is only slightly higher than that obtained for southern Finland (22.5; Puntila et al., 2013) and Iberia (20.25; Almeida et al., 2013), which themselves are close to the range of threshold values (18.0–19.8) from three different regions of the globe, i.e. the UK. (Copp et al., 2009), southern Japan (Onikura et al., 2012) and south-eastern Australia (Vilizzi and Copp, 2013). The high value of 20.25 for the Iberian peninsula has been attributed to a particularly low proportion of translocated species (18.0%, 16 of 89; Almeida et al., 2013), which is consistent with the Turkish situation (14.29%, 5 of 35). In contrast to both Iberia and Turkey, the high number of translocated fish species examined for the Balkans (44%, 19 of 43 species) could be the reason for a significantly lower threshold (9.5) in that geographical area (Simonović et al., 2013).

No species assessed for Turkey were classed as 'low risk' of being invasive, and ≈50% were categorized as 'medium risk', with the remainder being 'high risk'. Turkey and Iberia share a high level of endemism and therefore a heightened threat to native species diversity, with the introduced cyprinid fishes (*Carassius auratus*, *C. gibelio*, *Cyprinus carpio*) identified as posing the highest risk of being invasive (Almeida et al., 2013). These species are followed by the North American poeciliid species (*Gambusia affinis*, *G. holbrooki*) and the ictalurid catfishes (*Ameiurus melas*, *Ictalurus punctatus*).

As such, there appears to be greater similarity between Turkey and the Iberian peninsula, which is the western extent of the Mediterranean region, than between Turkey and the nearby Balkans region. However, a commonality of all three of these Mediterranean areas is the list of highest-scoring species (*Carassius gibelio*, icturalid catfishes, mosquitofishes), with *C. gibelio* being one of few species for which information exists regarding impacts on native fish communities (Tarkan et al., 2012a,b). Also ranking amongst the higher-risk species are two Asian fishes, namely, silver carp *Hypophthalmichthys molitrix* and *Pseudorasbora parva*. The former species has been categorised as high risk in North America (Kolar et al., 2005), and in some (Copp et al., 2009; Almeida et al., 2013) but not other (Mastitsky et al., 2010; Verbrugge et al., 2012) risk assessment areas. Whereas *P. parva* has been classified as high risk in all other risk assessment areas except for the Balkans, where it is categorized as medium risk (Simonović et al., 2013). However, a translocated fish species (*Atherina boyeri*), ranked as medium risk in the present study, may pose a greater risk than reflected by its ranking, given the species' rapid dispersal and establishment as a dominant species where introduced (Gençoğlu, 2010).

Similar to the Iberian and Balkans regions (Almeida et al., 2013; Simonović et al., 2013), the majority of species assessed for Turkey were classed *a priori* as either invasive or non-invasive, and not evaluated for their protection status (Fig. 2). These two groups include most of the highest-scoring species, emphasizing the threat posed by introduced species to native freshwater species and ecosystems of Turkey. The certainty associated with the assessments reflects the available published data on the species (Table 1), which are poor for *Pygocentrus nattereri* but currently extensive for *Pseudorasbora parva*. Similarly, the adverse impacts of mosquitofishes are well demonstrated, particularly in the Iberian peninsula (Caiola and de Sostoa, 2005; Alcaraz et al., 2008).

The coincidence rate between the two assessors for species rankings for Turkey was slightly higher (71%) than that obtained for Iberia (69%; Almeida et al., 2013), but in both of these studies there were significant differences among assessors in terms of their certainty of responses. This emphasizes the recommendation of Almeida et al. (2013) that each species be assessed by several independent researchers to obtain accurate and representative assessments for a particular region — an approach used in the calibration of FISK for the northern Kyushu Island, Japan (Onikura et al., 2012).

In conclusion, FISK has proved to be a useful tool for assessing risks posed by non-native fishes at the biogeographical frontier between Europe and Asia. Because of the very limited information on non-native freshwater fishes and insufficient effort in the implementation of risk analysis in both the European and Asian parts of Turkey, analyses in the present study focussed mainly on non-native freshwater fishes already present in Turkish waters. Further study is needed to identify the main introductory pathways of non-native fishes into Turkey so that, similar to Iberia (Almeida et al., 2013), potential species can be identified from their likely introductory pathways and then assessed for their invasiveness potential. This should include not only non-native species but also species translocated out of their native range within Turkey into other areas of the country. Finally, further monitoring is recommended for species such as *Cyprinus carpio*, which is regularly stocked throughout Turkey and thought to be responsible for the accidental introduction of other common non-native species (Önsoy et al., 2011).

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