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EUROPEAN LARGE LAKES IV

Risk assessment of non-native fishes in the catchment of the largest Central-European shallow lake (Lake Balaton, Hungary)

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Abstract The Fish Invasiveness Screening Kit (FISK) has proved to be a useful tool for assessing and screening the risk posed by potentially invasive fish species in larger risk assessment (RA) areas (i.e. country or multi-country level). In the present study, non-native freshwater fishes were screened for a smaller RA area, the closed and vulnerable but economically important drainage basin of Lake Balaton (Hungary). Receiver operator characteristic analysis of FISK scores for 26 fish species screened by four assessors identified 21 species with scores of ≥11.4 to pose a 'high risk' of being invasive, with five species ranked as 'medium risk' and none as 'low risk'. The highest scoring species were gibel carp *Carassius gibelio* and black bullhead *Ameiurus melas,* with three Ponto-Caspian *Gobiidae* identified as amongst the species posing the potentially greatest threat to the catchment. The results of the present study indicate that FISK can be applied to risk assessment areas of smaller geographical scale.

Keywords FISK · Shallow lakes · Invasibility · Hazard identification · Biological invasions

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Introduction

Lake Balaton is the largest shallow lake in Central Europe. The lake and its catchment are considered to be one of the most economically important regions of Hungary, providing essential ecosystem services such as angling tourism, which has increased continuously across the catchment. The populations of target native species, i.e. common carp *Cyprinus carpio* and pikeperch *Sander lucioperca*, are strongly dependent upon the stocking and abundance of non-native species (Specziár & Turcsányi, 2014). Also, the opening of the Sió Canal in the 1860s connected the Balaton basin with that of the River Danube (Korponai et al., 2010; Zlinszky & Tímár, 2013), resulting in several biological invasions (Bíró, 1972; Muskó et al., 2008; Benkő-Kiss et al., 2013).

Based on the list of native species given in Herman (1887), the first non-native fish to have invaded the Balaton basin (via the Sió Canal) was tubenosed goby *Proterorhinus semilunaris*, which is native to the lower Danube, followed by introductions in the late 19th century of three North American fishes, pumpkinseed *Lepomis gibbosus*, rainbow trout *Oncorhynchus mykiss* and mosquitofish *Gambusia affinis*, and also European eel *Anguilla anguilla*. These species were introduced for aquaculture (rainbow trout, eel), ornamental purposes (pumpkinseed) and mosquito control (Herman, 1890; Vutskits, 1897; Györe, 1995). Being intolerant to colder temperatures, the mosquitofish has not dispersed from its original introduction site, the thermal lake at Héviz (Specziár, 2004). The next wave of introductions to Lake Balaton occurred in the 1960s and involved several species of Far-Eastern origin. At present, 12 of the 42 fish species (29%) in the Balaton catchment are non-native (Takács et al., 2011), which is amongst the highest in Europe (Economidis et al., 2000; Copp et al., 2005a; Povž & Šumer, 2006; Koščo et al., 2010; Lusk et al., 2010; Almeida et al., 2013).

The distribution, abundance and related impact on the native ecosystem by these non-native species vary strongly even at local geographical scales (Erős et al., 2009; Sály et al., 2011; Ferincz et al., 2012, 2014; Paulovits et al., 2014), and the possibility of further introductions is still high. For this reason, there is an urgent need to identify those species that are likely to pose a high risk to the Balaton catchment. The aims of the present study were therefore to (1) undertake a risk screening of non-native species using version 2 (Lawson et al., 2013) of the Fish Invasiveness Screening Kit (FISK; Copp et al., 2009) so as to inform environmental managers of which non-native species pose the greatest risk of being invasive in the Balaton catchment; and (2) evaluate the applicability of FISK to smaller risk assessment (RA) areas than those (country or regional scales) for which it has been used in the past (Copp, 2013).

Materials and methods

The RA area, the Lake Balaton catchment (Fig. 1), is located in West Hungary (Transdanubia), has an area of 5775 km^2 and is characterised by a humid continental climate (Köppen–Geiger type Dfb: Peel et al., 2007). The Balaton catchment supports stable populations of several species listed in the Bern Convention (Annexes II and III) and Habitats Directive (Annexes II, IV and V), such as razorfish *Pelecus cultratus*, asp *Aspius aspius*, Volga pikeperch *Sander volgensis* and the endemic European mudminnow *Umbra krameri* (Specziár et al., 2010; Takács et al., 2015).

Altogether, 26 non-native species were assessed for their potential to represent a threat for the RA area using FISK v2 (Lawson et al., 2013), and their selection was based on the following two criteria: (1) the species has already been reported from the Balaton catchment (Takács et al., 2011); and (2) the species occurs within the territory of Hungary (Harka & Sallai, 2004; Halasi-Kovács et al., 2011), which is taken to represent the primary donor area. Of the species assessed, 12 (46%) corresponded to criterion 1 and 14 (54%) to criterion 2 (Table 1).

FISK v2 (Lawson et al., 2013) was chosen because of its widespread usage, relative simplicity and 'policy-maker friendly' output (Copp, 2013). Briefly, FISK v2 relies on 49 questions in total that assess the potential risk of a species being invasive and are arranged according to eight topics: domestication/cultivation, climate and distribution, invasive elsewhere, undesirable traits, feeding guild, reproduction, dispersal mechanism and persistence attributes. Importantly, in this study, definition of the RA area (the Lake Balaton catchment) was based on biogeography considerations instead of political boundaries (as done for most previous FISK applications), and this is consistent with non-native species risk analysis

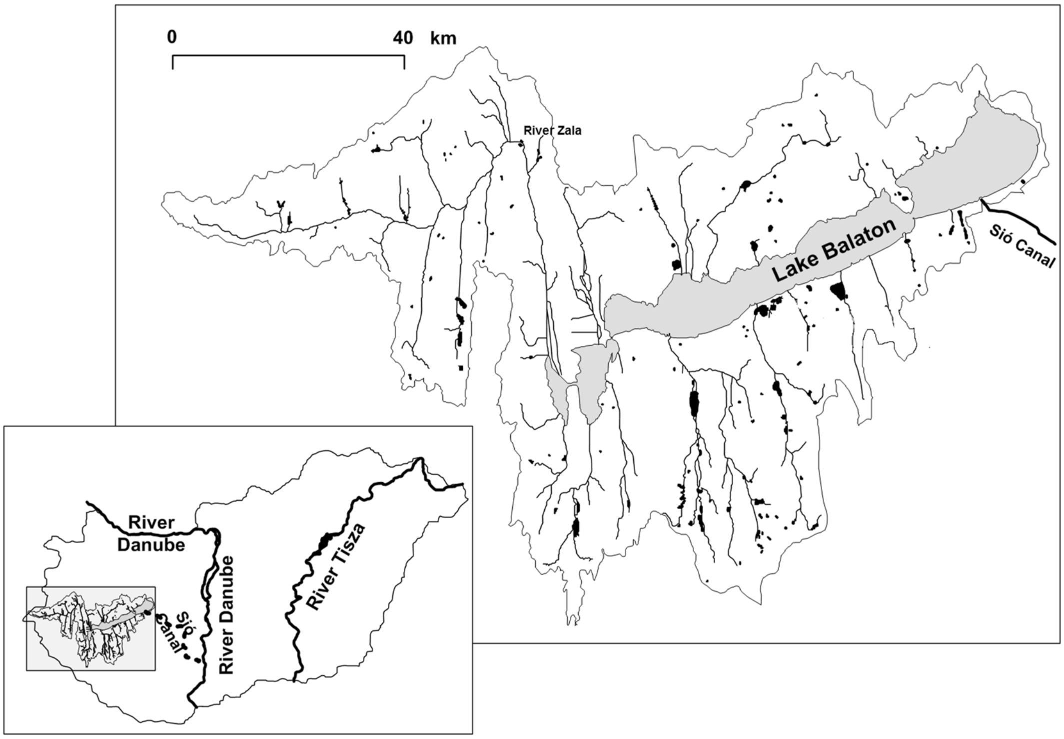

Fig. 1 Map of the Balaton catchment (Hungary), with indication of the main inflow (River Zala) and outflow (Sió Canal)

guidelines (e.g. EPPO, 2002) and more generally agrees with the non-native species concept (Copp et al., 2005b).

Assessments of the 26 species were carried out independently by four assessors (AF, AS, AW, and PT), who have knowledge of the distribution and ecology of fishes within the risk assessment area. Receiver operating characteristic (ROC) curves analysis was used to assess the predictive ability of the FISK tool, with the final objective to determine a threshold score for discriminating between non-invasive and invasive species. Since a priori categorization of the species is needed for this test, FishBase (http://www.fishbase.org/home.htm) and the database of Invasive Species Specialist Group (http://www.issg.org/) were used to categorise the species a priori as 'invasive' or 'non-invasive'. Four independent ROC curves were then constructed for the four assessors, and differences between these curves were statistically assessed using the Venkatraman (2000) method. Following between-curve comparison, a global ROC curve was computed on the mean scores from all 26 species evaluated.

Statistically, a ROC curve is a graph of sensitivity versus 1 minus specificity (1—specificity), and in the present context the sensitivity of the FISK test will be the proportion of invasive fish species that are correctly identified by the test, whereas specificity refers to the proportion of non-invasive species that are correctly identified as such. An important measure of the accuracy of the calibration analysis is the area under the ROC curve. If this area is equal to 1.0, then the ROC curve consists of two straight lines, one vertical from 0.0 to 0.1 and the next horizontal from 0.1 to 1.1. In such cases, the test is 100% accurate because both the sensitivity and specificity are 1.0, so there are no false positives or false negatives. On the other hand, a test is not accurate if the ROC curve is a diagonal line from 0.0 to 1.1. The ROC area for this line is 0.5, with ROC curve areas typically being between 0.5 and 1.0 (Copp et al., 2009). The best FISK threshold (cut-off) value that maximises the true positive rate (true invasive classified as invasive) and minimises the false positive rate (true non-invasive classified as invasive) was determined using a combination of Youden's J statistic (Youden, 1950) and

Table 1 Fish species assessed with FISK v2 for the Balaton-catchment. For each species, a priori invasiveness (as per http://www.issg.org/ and http://www.fishbase.org) and protection status, along with corresponding FISK score and certainty factor (CF), are reported

Species name	Common name	Origin	Invasiveness/protection status	Criterion	Score					Certainty factor			
					Mean	Min	Max	SE	Outcome	Mean	Min	Max	SE
Acipenser baerii	Siberian sturgeon	Asia (Siberia)	Non-invasive/endangered	1	9.25	5.5	12.0	1.53	M	0.77	0.7	0.8	0.01
Ameiurus melas	Black bullhead	North-America	Invasive/not evaluated	1	29.00	25.0	33.0	2.31	H	0.87	0.8	0.9	0.03
Ameiurus nebulosus	Brown bullhead	North America	Invasive/least concern	1	23.00	16.0	30.0	6.42	MH	0.82	0.8	0.9	0.27
Anguilla anguilla	European eel	Europe	Non-invasive/critically endangered	1	15.25	14.0	17.0	0.75	MH	0.88	0.9	0.9	0.01
Archocentrus multispinosus	Rainbow cichlid	South America	Non-invasive/not evaluated	2	7.00	3.0	16.0	3.02	M	0.88	0.8	0.9	0.04
Babka gymnotrachelus	Racer goby	Ponto-Caspian	Non-invasive/least concern	2	17.50	14.0	20.0	1.32	MH	0.88	0.9	0.9	0.03
Carassius gibelio	Gibel carp	Far-East	Invasive/not evaluated	1	35.75	30.0	40.0	2.17	VH	0.87	0.8	0.9	0.03
Clarias gariepinus	North African catfish	North Africa	Invasive/least concert	2	12.63	5.0	18.0	2.78	MH	0.81	0.8	0.9	0.04
Ctenopharyngodon idella	Grass carp	Far-East	Non-invasive/not evaluated	1	17.63	12.0	23.0	2.36	MH	0.83	0.8	0.9	0.03
Gambusia holbrooki	Eastern mosquitofish	North-America	Invasive/not evaluated	1	11.50	7.0	14.5	1.67	H	0.84	0.7	0.9	0.08
Gasterosteus aculeatus	Threespine stickleback	Europe	Non-invasive/least concern	2	11.13	4.5	17.0	2.63	M	0.79	0.7	0.8	0.26
Hypophthalmichthys molitrix × *H. nobilis*	Asian carp hybrid	Far-East	Invasive/near threatened	1	23.38	6.0	21.0	3.33	MH	0.85	0.6	0.9	0.07
Ictalurus punctatus	Channel catfish	North-America	Invasive/least concern	2	8.67	4.0	15.0	2.33	M	0.78	0.8	0.9	0.26
Ictiobus bubalus	Smallmouth buffalo	North-America	Non-invasive/least concern	2	13.63	11.0	26.0	3.14	MH	0.74	0.7	0.9	0.07
Knipowitschia caucasica	Caucasian dwarf goby	Ponto-Caspian	Non-invasive/least concern	2	10.25	7.0	20.0	2.43	M	0.81	0.8	1.0	0.03
Lepomis gibbosus	Pumpkinseed	North-America	Non-invasive/not evaluated	1	19.25	8.0	22.0	3.50	MH	0.81	0.8	0.9	0.05
Micropterus salmoides	Largemouth bass	North-America	Invasive/least concern	2	12.75	10.0	20.0	2.95	MH	0.87	0.7	1.0	0.06
Mylopharyngodon piceus	Black carp	Far-East	Invasive/data deficient	2	15.38	20.5	26.0	2.88	MH	0.83	0.8	1.0	0.03

Table 1 continued

Species name	Common name	Origin	Invasiveness/protection status	Criterion	Score					Certainty factor			
					Mean	Min	Max	SE	Outcome	Mean	Min	Max	SE
Neogobius fluviatilis	Monkey goby	Ponto-Caspian	Non-invasive/not evaluated	1	14.88	8.0	17.0	2.11	MH	0.85	0.6	1.0	0.08
Neogobius melanostomus	Round goby	Ponto-Caspian	Invasive/least concern	2	22.38	5.0	19.5	1.25	MH	0.87	0.8	1.0	0.06
Oncorhynchus mykiss	Rainbow trout	North-America	Invasive/not evaluated	1	12.00	23.0	27.0	1.96	MH	0.79	0.7	1.0	0.09
Oreochromis niloticus	Nile tilapia	North-Africa	Invasive/not evaluated	1	12.88	14.5	24.0	3.04	MH	0.88	0.8	1.0	0.06
Perccottus glenii	Amur (Chinese) sleeper	Far-East	Non-invasive/vulnerable	1	24.50	5.0	19.0	0.87	MH	0.88	0.8	0.9	0.07
Ponticola kessleri	Kessler's goby	Ponto-Caspian	Non-invasive/least concern	2	18.25	21.0	30.0	2.15	MH	0.89	0.9	0.9	0.05
Proterorhinus marmoratus	Tubenose goby	Ponto-Caspian	Non-invasive/least concern	1	11.50	7.0	11.0	2.90	MH	0.85	0.8	0.8	0.04
Pseudorasbora parva	Topmouth gudgeon	Far-East	Invasive/not evaluated	1	25.00	6.0	21.0	1.96	H	0.85	0.6	0.9	0.00

Outcome is based on a calibration threshold of 11.75 between medium and high risk species sensu lato. Criterion *1* already occurring in the catchment; *2* not reported from the catchment yet, but occurring within the territory of Hungary (see text for computations) the point closest to the top-left part of the plot with perfect sensitivity or specificity. For the global (mean) 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 (0–1, at 0.1 intervals).

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

$$\Sigma(\mathrm{CQ}i)/(4 \times 49) \quad (i = 1, \ldots, 49)$$

where CQi is the certainty for question i, 4 is the maximum achievable value for certainty (i.e. 'very certain'), and 49 is the total number of questions comprising the FISK tool. The CF therefore ranges from a minimum of 0.25 (i.e. all 49 questions with certainty score equal to 1) to a maximum of 1 (i.e. all 49 questions with certainty score equal to 4). Analyses were carried out with package pROC for R statistical environment (R Development Core Team, 2015; Robin et al., 2011) and 2000 bootstrap replicates were used.

Results

There were no statistical differences between the four assessor-specific ROC curves and corresponding AUCs (Venkatraman permutation tests: Table 1; Fig. 2a). As a result, a global ROC curve could be computed based on mean FISK scores, which resulted in an AUC of 0.7005 (0.5226–0.9224 95% CI), hence above 0.5 (Fig. 2b). This indicated that FISK was able to discriminate reliably between invasive and non-invasive species for the Balaton catchment. Since Youden's J and closest top-left statistics provided slightly different values (i.e. $\approx$11.4 and $\approx$11.9, respectively), the smallest one was chosen as calibration threshold of the FISK risk outcomes for the Balaton catchment (Table 2). Based on this threshold, 'medium risk' species were regarded as those with scores within the interval [1; 11.4] and 'high risk sensu *lato*' species those with scores within the interval [11.4; 57], with the latter further categorised as per Britton et al. (2010a) into 'moderately high risk' (interval [11.4, 25]), 'high risk' (interval [25,30]), and 'very high risk' (interval [30, 57]). Species categorised as 'low risk' were those attributed a FISK score within the interval [−15, 1] (NB: open square brackets indicate an open interval).

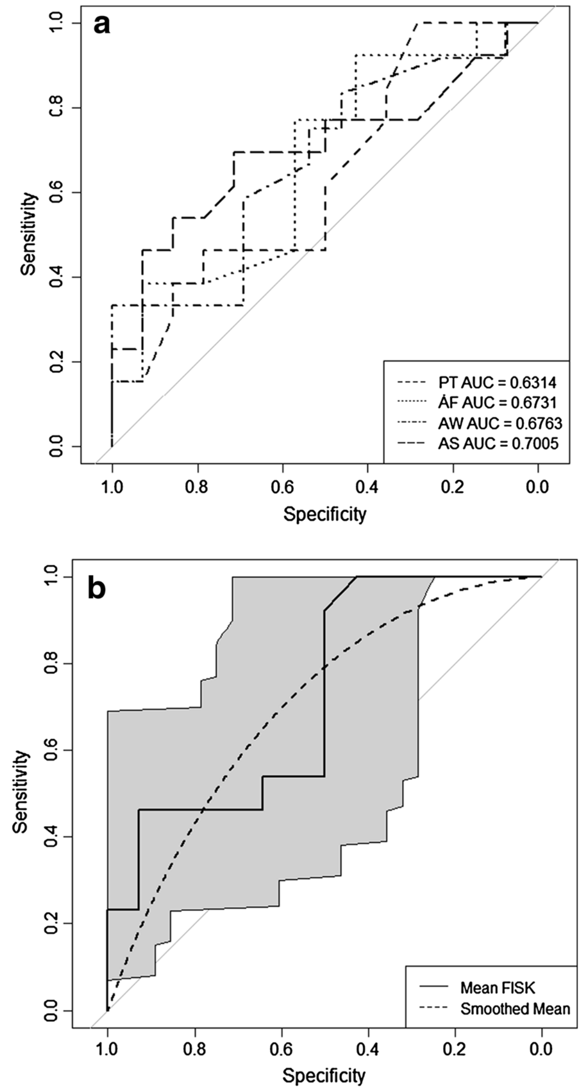

Fig. 2 **a** Receiver operating characteristic (ROC) curves for four assessors (AF, AS, AW and PT) on 26 fish species assessed by FISK for the Balaton catchment. **b** Mean ROC curve based on mean scores from the four assessors, with smoothing line and confidence intervals of specificities (see Table 1)

Based on the 11.4 threshold score and corresponding intervals, none of the mean scores for the 26 species fell into the 'low risk' category, whereas five (19.2%) were categorised as 'medium risk', and the remaining 21 (80.7%) as 'high risk' sensu lato of which 18 (85.7%, 69.2%; of total) as 'moderately high risk', two (9.5%; 7.4% of total) as 'high risk' (topmouth gudgeon *Pseudorasbora parva* and black

Table 2 *P* values for Venkatraman's permutation tests comparing the AUCs of the four ROC curves from the four independent assessments

Assessor	AF	AS	AW	PT
AF	–	0.283	0.875	0.633
AS		–	0.709	0.205
AW			–	0.216
PT				–

bullhead *Ameiurus melas*), and one (4.8%; 3.7% of the total) as 'very high risk' (gibel carp *Carassius gibelio*; Table 2). The lowest-scoring species was the rainbow chichlid *Archocentrus multispinosus*.

Mean and median scores according to the different selection criteria showed significant differences ($t = -3.48$, df $= 99.9$, $P = 0.0007$), with non-native species already inhabiting the catchment scoring higher. Amongst the Criterion 1 species, the highest scoring were the round goby *Neogobius melanostomus*, bighead goby *Ponticola kessleri*, and the racer goby *Babka gymnotrachelus*. The median FISK score in each group (i.e. criteria 1 and 2) was higher than the 11.4 threshold (Fig. 3). Mean scores for all species classified *a priori* as invasive were ranked as 'high risk sensu *lato*' and fell into the 'moderately high risk' sub-

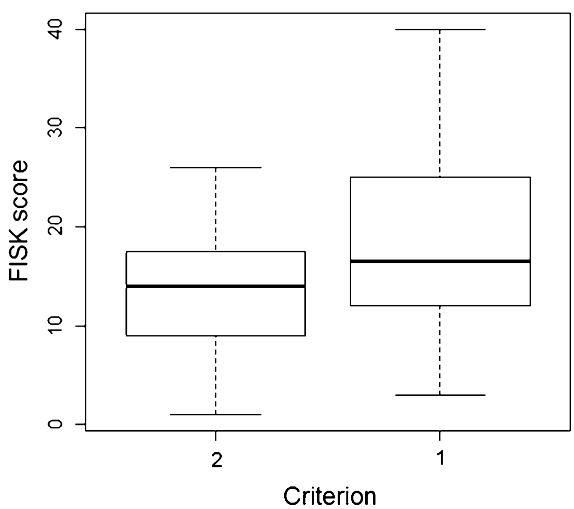

Fig. 3 *Boxplots* of mean FISK scores according to species' selection criteria: *1* already occurring in the catchment; *2* not yet reported from the catchment, but occurring within the territory of Hungary

category. However, the mean scores for non-invasive species both of least concern and vulnerable threat status also were ranked as 'moderately high risk', with only the non-invasive endangered Siberian sturgeon *Acipenser baerii* classified as 'medium risk' (Fig. 4).

Mean certainty in response for all species was 3.36 ± 0.3 SE (i.e. above the category "mostly certain") and CF was 0.84 ± 0.09 SE, and ranged from a minimum of 2.52 ± 0.1 SE (CF: 0.63 ± 0.01 SE) for channel catfish *Ictalurus punctatus* and rainbow trout to a maximum of 3.88 ± 0.4 SE (CF: 0.97 ± 0.08 SE) for monkey goby *Neogobius fluviatilis* and round goby (Table 1).

Discussion

The threshold value of 11.4 obtained in the present study was overall consistent with those for previous FISK-based assessments in neighbouring areas, namely the southern (threshold = 9.5: Simonović et al., 2013) and northern (threshold = 11.8: Piria et al., 2015) Balkans countries. Conversely, the Lake Balaton FISK threshold value was lower than those obtained for RA areas elsewhere worldwide, ranging from 15.3 to 24 (Copp et al., 2009; Verreycken et al., 2009; Onikura et al., 2011; Vilizzi & Copp, 2012; Almeida et al., 2013; Puntila et al., 2013; Tarkan et al., 2014; Perdikaris et al., 2015; Mendoza et al., 2015). The lower threshold values in the Balkans region, where within-region and/or between-catchment translocations have occurred, have been attributed to the elevated proportion of endemic species (Simonović et al., 2013; Piria et al., 2015). Locally translocated species (those native to one part of the RA area and introduced outside their native range within the RA area) tend to be less invasive than more exotic species (those from other continents), and this is likely the reason for the lower threshold values. The reason for the low score threshold in the Balaton catchment could be attributed to a scale-dependent effect, given that this RA area is much smaller than the RA areas of previous FISK applications, where entire countries, regions, or very large river catchments were considered (Copp, 2013).

The taxonomic profiles of the highest scoring species showed overall similarities to previous studies, with cyprinids and ictalurid catfishes being ranked as high risk (Mastitisky et al., 2010; Almeida et al., 2013;

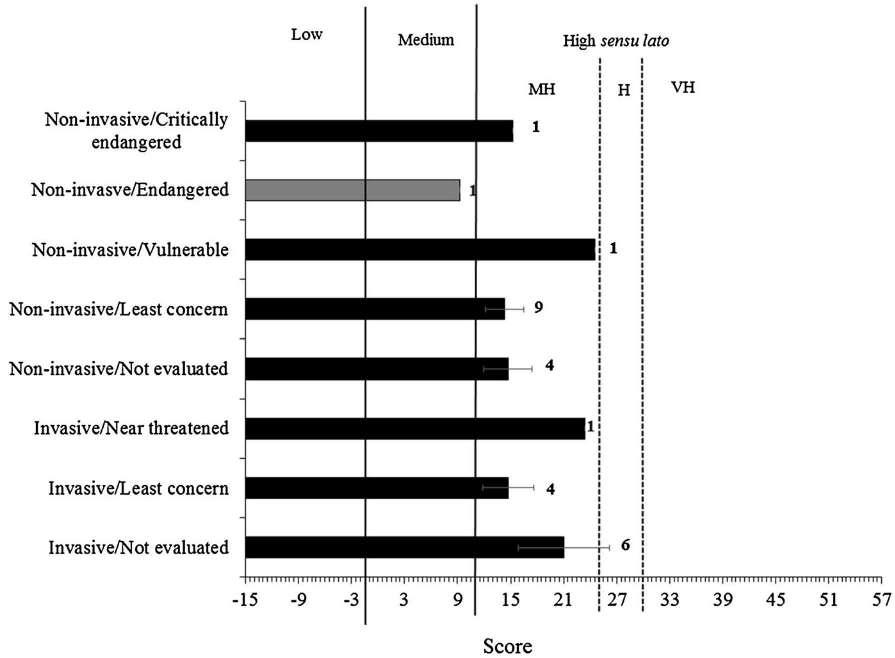

Fig. 4 Mean scores (±SE and *n*) for 26 fish species assessed by FISK for the Balaton-catchment and ranked according to their a priori invasiveness and protection status (cf. Table 1). Thresholds are: <1 (low risk) and ≥11.375 (high risk sensu lato), with medium risk species in between. Risk categories and [lower, upper] scores are: *L* low risk [−15, 1], *M* medium risk [1, 11.375], *MH* moderately high risk [11.375, 25], *H* high risk [25, 30], *VH* very high risk [30, 57]

Puntila et al., 2013; Tarkan et al., 2014; Perdikaris et al., 2015; Piria et al., 2015). Gibel carp received the highest score, similar to FISK assessments elsewhere in Europe and Asia Minor. This species, native to the Far East (Bănărescu, 1990), has a long history of invasiveness and its establishment in the Danube system could have occurred in two ways. Firstly, Holčík (1980) hypothesised that gibel carp expand across Romania by natural dispersal, but (secondly) stocks were also known to have been imported previously from Bulgaria to Szarvas (Eastern Hungary) for aquaculture (Szalay, 1954). The first report of gibel carp for the Hungarian section of the Danube was in 1975 (Tóth, 1975), with its introduction to Lake Balaton occurred in the same period (Bíró, 1997), and the species is currently present virtually throughout the Balaton catchment, with extremely high abundances in wetlands, angling ponds and canals (Ferincz et al., 2016).

Black bullhead scored second highest in the present study. With the exception of Finland (Puntila et al., 2013), this high risk ranking is consistent with FISK assessments elsewhere, including Europe (Copp et al., 2009; Verreycken et al., 2009; Mastitsky et al., 2010; Almeida et al., 2013; Perdikaris et al., 2015; Piria et al., 2015), Asia Minor (Tarkan et al., 2014) and the Murray-Darling basin, Australia (Vilizzi & Copp, 2012). Tolerant of harsh water conditions (e.g. pollution, low dissolved oxygen levels), this nest-guarding species is omnivorous and aggressive (Braig & Johnson, 2003; Novomeská & Kovác, 2009). Black bullhead was first reported in Europe, in France, in 1871, where it was imported for aquaculture (Coucherousset et al., 2006), and it has since expanded its invasive range to become the most widespread North American ictalurid catfish of Europe (Pedicillo et al., 2008). The species' expansion has been human mediated and fast in some cases (e.g. to Hungary from Italy in 1980: Harka, 1997). In other European locations, however, dispersal has been slower, such as in Spain (first record in 1984: Elvira, 1984), Portugal (first record in 2002; Gante & Santos, 2002), and England, where the only recently confirmed population has been present for >50 years (Wheeler et al., 2004) but was eradicated in 2014 (GB Non-native Species Secretariat, 2014). Yet, despite achieving a high score, its abundance and frequency of occurrence is still generally low across the Balaton catchment (Erős et al., 2009; Sály et al., 2011; Paulovits et al., 2014; Ferincz et al., 2016).

Topmouth gudgeon was also categorised as 'high risk', similar to all other European and Asia Minor assessments. This small, mainly planktivorous fish, which is regarded as the most invasive species in Europe (Gozlan et al., 2005, 2010), is native to the Far

East (i.e. China, Korea and western regions of Japan, and its introduction to Europe (including Hungary) and Middle Asia occurred accidentally in 1960–1962 as a contaminant of larvae of large herbivorous cyprinids (i.e. *Hypophthalmichthys* sp. and grass carp *Ctenopharyngodon idella*) imported to Romania from China (Bănărescu, 1964). A continental-scale invasion then took place in the 1970–1980s, and currently the species is widespread throughout Europe (Gozlan et al., 2010). Extremely high abundances are often found in small angling ponds, nursing ponds and canals of pond aquaculture facilities (Adamek & Siddiqui, 1997; Rosecchi et al., 2001; Britton et al., 2010b), and there is increasing evidence of its impacts on native fishes (e.g. Britton et al., 2007, 2009, 2011; Gozlan et al., 2005, 2010). For example, competition for spawning grounds with the endangered *Pseudorasbora pumila* has been observed in Japan (Konishi & Takata, 2004) and trophic overlaps with roach *Rutilus rutilus* and rudd *Scardinius erythrophthalmus* have been reported (Britton et al., 2010c). Specific to the Balaton catchment, topmouth gudgeon is found in every habitat with the highest abundances recorded in angling and fish ponds (Sály et al., 2011; Paulovits et al., 2014; Ferincz et al., 2015).

According to current assessment, the Amur sleeper *Perccottus glenii* was categorised as ‘moderately high risk’, in spite of recent studies having highlighted this species as the most threatening for the native fish communities of the Carpathian Basin (Kati et al., 2015; Takács et al., 2015). Currently, the status of this species is confusing, as it is classed as ’Vulnerable’ in its native range, but also considered to be the most invasive species in Central Europe. The invasion of this small odontobutid (Perciformes: *Odontobutidae*) species is well documentated (Terlecki & Palka, 1999; Harka & Sallai, 1999; Koščo et al., 2003; Nalbant et al., 2004; Reshetnikov, 2004; Simonović et al., 2006; Jurajda et al., 2006; Nowak et al., 2008), its native range is the Russian Far East and the northern part of the Korean Peninsula and the potential Holarctic distribution was modelled by Reshetnikov & Ficetola (2011). The introduction and expansion of Amur sleeper in Europe started with two introduction events, namely in St. Petersburg in 1912 and Moscow in 1948, both as releases from aquaria (Koščo et al., 2003). The first Hungarian specimen of the Amur sleeper was collected in 1997 in the middle section of the River Tisza (Harka, 1998), and the species has since invaded the highly vegetated irrigation canals, oxbow lakes and other lentic habitats of the river catchment (Harka & Sallai, 1999). At the time, the species was expected to require decades to reach the Transdanubian region (Erős et al., 2008). However, the first specimens were caught in the Balaton-catchment in 2008 (Erős et al., 2008) and reached the mouth of the main inflow of River Zala in 2012 (Takács et al., 2012). As the Amur sleeper has been known to extirpate populations of the endemic, strictly protected European mudminnow (Kati et al., 2015; Takács et al., 2015) and amphibians, aquatic macroinvertebrates (Reshetnikov, 2003, 2008). Therefore, the effective risk posed by this non-native species is considered to be higher than indicated by the current risk assessment.

Similarly to Turkey (Tarkan et al., 2014), the Iberian Peninsula (Almeida et al., 2013), Greece (Perdikaris et al., 2015) and Northern Balkan countries (Piria et al., 2015), no species in the present study were categorised as at ‘low risk’ of being invasive. This finding is in agreement with the ‘invasion sensitivity’ of this small and closed catchment (Bíró, 1972; Muskó et al., 2008; Benkő-Kiss et al., 2013). The significantly higher scores of the species already present in the catchment indicated that species with higher invasive potential are already present in the RA area. In this respect, the potentially most threatening species were those from Criterion 2, and included three Ponto-Caspian gobies (i.e. round goby, racer goby, bighead goby). These species have a long invasion history throughout Europe and North America (Kornis et al., 2012; Roche et al., 2013), and the Sió Canal may represent an important invasion corridor from river Danube. For this reason, appropriate management measures are required of the Sió floodgate to prevent the passage of this species into Lake Balaton.

In conclusion, a successful risk screening was carried out for the small and isolated catchment of Lake Balaton. The most threatening non-native species were identified using FISK v2. These results pointed out the necessity and possibility of damming further invasions and might be a basis of planning the further fish stock management issues of the RA area.

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