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Risk Assessment

Invasiveness risks of the shimofuri goby (*Tridentiger bifasciatus*) in Great Britain

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Abstract

Invasive species risk assessment tools are a vital means of identifying taxa likely to be introduced and cause adverse effects within a specified area, allowing for the preparation of targeted management strategies. Following the first report of the shimofuri goby (*Tridentiger bifasciatus*) in Europe, a risk assessment was undertaken for this species for Great Britain using the Aquatic Species Invasiveness Screening Kit (AS-ISK). This was achieved by the completion of two risk screenings, one undertaken for England and Wales, and another for Scotland. The results of this assessment place the shimofuri goby in a category of medium risk for both assessed areas. The shimofuri goby's adaptable nature and ability to change its reproductive strategy in response to climatic conditions increase the likelihood of the species persisting and proliferating within the area after introduction. However, the species' inability to survive in marine salinities reduced the score for likelihood of its introduction, and its small size and generalist nature coupled with a lack of available evidence made the prediction of specific impacts difficult. In addition, the extent of suitable habitat for this species is likely to expand throughout Great Britain under predicted climate change, thus increasing the risk of its establishment and potential impacts..

Key words: AS-ISK, brackish, euryhaline, freshwater, Gobiidae, invasive fish, non-native fish

Introduction

The introduction of a non-native fish can have varying consequences on native taxa and ecosystems (Britton 2023), with cascading impacts through the food web (Makarewicz et al. 2016; Pagnucco et al. 2016). To provide environmental managers with information on potential environmental threats prior to a species' arrival, it is important to carry out risk identification (risk screening) to inform decisions on early detection, rapid response and management measures (Britton et al. 2011). Such pre-emptive risk identification

is vital because freshwater and estuarine habitats are particularly susceptible to the impacts of non-native fishes (Fabrizio et al. 2021; Glamuzina et al. 2021). However, the comprehensiveness of these assessments is often limited by a lack of available information on the early phases of biological invasions (Marsico et al. 2010), including factors affecting certain species' failure to establish non-native populations in certain areas (Copp et al. 2007; Zenni and Nuñez 2013).

An example of a recent pre-emptive assessment for Great Britain (GB) is the risk screening of the naked goby *Gobiosoma bosc* (Lacépède, 1800), in response to the species' appearance in coastal waters of the eastern North Sea (Belgium, Germany, Netherlands). This assessment placed the species in the low-medium invasiveness risk category across the east coast of GB (Dodd et al. 2022). Another goby species, the shimofuri goby *Tridentiger bifasciatus* Steindachner, 1881, has recently been reported in Belgium (Verhelst and Verreycken 2023). It is therefore important to assess the likelihoods, under current and future climate conditions, of the shimofuri goby appearing in GB, establishing a self-sustaining population, dispersing more widely, and exerting impacts.

The shimofuri goby is a euryhaline fish native to eastern Asia, including regions of China, South Korea, and Japan (Qin et al. 2020a). This species has been introduced to and has successfully established breeding populations in two different regions in recent decades, the first being a network of reservoirs and lakes in eastern China (Qin et al. 2020a, b), and the second including a range of estuarine and freshwater environments in the western United States of America (USA) (Meng et al. 1994; Matern 1999; Matern 2001; Howard and Booth 2016). The two specimens of this species reported in Belgium, the first such report for Europe, were found in the Gent–Terneuzen shipping canal (Verhelst and Verreycken 2023). The unexpected appearance of the shimofuri goby in a North Sea neighbouring country serves as a reminder of the unpredictable nature of species introductions and highlights the need for a risk screening of this species to be undertaken for GB. Indeed, despite no indication of the shimofuri goby being present in GB at the time of this assessment, the completion of a risk screening can serve to ensure a more targeted and effective management response, should the species be introduced (Britton et al. 2011).

The aim of the present study was to undertake a risk screening and habitat suitability assessment of the shimofuri goby for GB, to inform environmental managers and policy makers of any potential threats posed by this species should it be introduced to GB coastal rivers and associated waters. This assessment was undertaken through two separate risk screenings, one for England & Wales and another for Scotland, providing both an overall screening for GB, and information on potential differences in the species' invasiveness in these risk assessment areas.

Materials and methods

The risk assessment for the shimofuri goby's potential invasiveness in Great Britain was undertaken using the Aquatic Species Invasiveness Screening Kit (AS-ISK), which is available for free download at www.cefas.co.uk/nns/tools/. This electronic decision-support tool was developed to standardise and streamline risk screenings for aquatic taxa (Copp et al. 2016) and has been extensively tested in a global trial (Vilizzi et al. 2021). The tool comprises of a series of 55 questions, the first 49 of which form the Basic Risk Assessment (BRA), assessing the studied taxon's biological characteristics to estimate the likelihood of its arrival and establishment within the risk assessment (RA) area. The assessment questions also allow for the evaluation of the taxon's potential impacts within the RA areas on native species, the surrounding environment, and ecosystem services. The final six questions comprise the Climate Change Assessment (CCA), which serve to assess the species' responses to changing environmental conditions, and how these may affect the species' establishment, distribution and impacts within the RA areas in the future.

Two separate assessments were performed by different assessors for the shimofuri goby: the first assessor (LP) undertook a risk assessment for England and Wales, and the second (JD) for Scotland. Within these areas, all freshwater, brackish and marine environments were considered. Once the two screenings were completed, both were reviewed by a third investigator (PD), and a meeting was held to discuss any discrepancies in the results which were due to differences in interpretation of the questions (as opposed to genuine differences between the two RA areas). A few minor modifications to the assessors' answers were made following this quality control process.

To enable comparison of the shimofuri goby's invasiveness with that of other non-native fishes in GB, the Basic Risk Assessment scores (BRA) for both RA areas were judged against the threshold developed by Dodd et al. (2019), who defined the limit between classification as medium or high risk as a BRA score ≥21.0. This threshold was chosen as it was specifically designed to be used in the risk assessment for non-native fishes in Great Britain, thus providing more accurate results for this assessment. As recommended by Vilizzi et al. (2022), only the BRA scores were considered for this assessment of score against threshold, rather than the BRA+CCA values, to reduce the likelihood of incorrect risk classifications caused by the climate change questions.

Climate suitability for this species in the RA areas was primarily assessed using Koppen-Geiger Climate Classification (Peel et al. 2007). This system was used to compare the climate of the species' native and non-native ranges with that of Great Britain. In addition, Climatch (Australian Bureau of Rural Sciences 2020) scores comparing the species' native and non-native ranges to the RA areas were considered, to provide an overall value for their similarities.

Table 1. A summary of the AS-ISK scores and summary statistics for two risk assessments undertaken for the shimofuri goby: the first for England and Wales, and the second for Scotland. Scores are separated into three categories, according to the assessed traits or impacts (full details in AS-ISK user manual). Summary statistics are presented as emboldened values in lower rows.

	Risk Assessment 1 – England & Wales	Risk Assessment 2 – Scotland
Score Partition		
A. Biogeography/Historical	−1.0	−1.0
1. Domestication/Cultivation	−2.0	−2.0
2. Climate, distribution and introduction risk	3.0	3.0
3. Invasive elsewhere	−2.0	−2.0
B. Biology/Ecology	18.0	13.0
4. Undesirable (or persistence) traits	5.0	5.0
5. Resource exploitation	7.0	2.0
6. Reproduction	3.0	3.0
7. Dispersal mechanisms	2.0	2.0
8. Tolerance attributes	1.0	1.0
C. Climate change	4.0	4.0
9. Climate change	4.0	4.0
Statistics – Sectors affected		
Commercial	**4**	**4**
Environmental	**6**	**1**
Species or population nuisance traits	**17**	**17**
Statistics – Scores		
BRA	**17.0**	**12.0**
BRA+CCA	**21.0**	**16.0**
Statistics – Confidence Thresholds		
BRA+CCA	**0.51**	**0.52**
BRA	**0.53**	**0.53**

Information from the Freshwater Environments of the World online database was used to compare the two RA areas (England & Wales; Scotland) considered for this screening. Finally, the results of climate mapping by Chen et al. (2024) were used in the quantification of current and potential future distributions of suitable habitat for the shimofuri goby throughout Great Britain.

Results and discussion

Results

The BRA scores were 17.0 for England & Wales and 12.0 for Scotland (Table 1), with most of the divergence coming from the questions on resource exploitation (i.e. impact on the environment), as shown in Figure 1. These scores suggest a categorisation of medium risk for the shimofuri goby in both RA areas, as both values are below the threshold value of BRA ≥21.0, as developed by Dodd et al. (2019) for freshwater fishes in GB.

The results for the CCA questions 50 to 55 were identical in the two assessments (Table 1; Supplementary material Tables S1, S2), implying that the effects of climate change on the chance of arrival, establishment and impacts of this species are likely to be similar in the two RA areas. In both cases, the shimofuri goby's invasiveness risk was predicted to increase under climate change, due to an increased risk of establishment and dispersal.

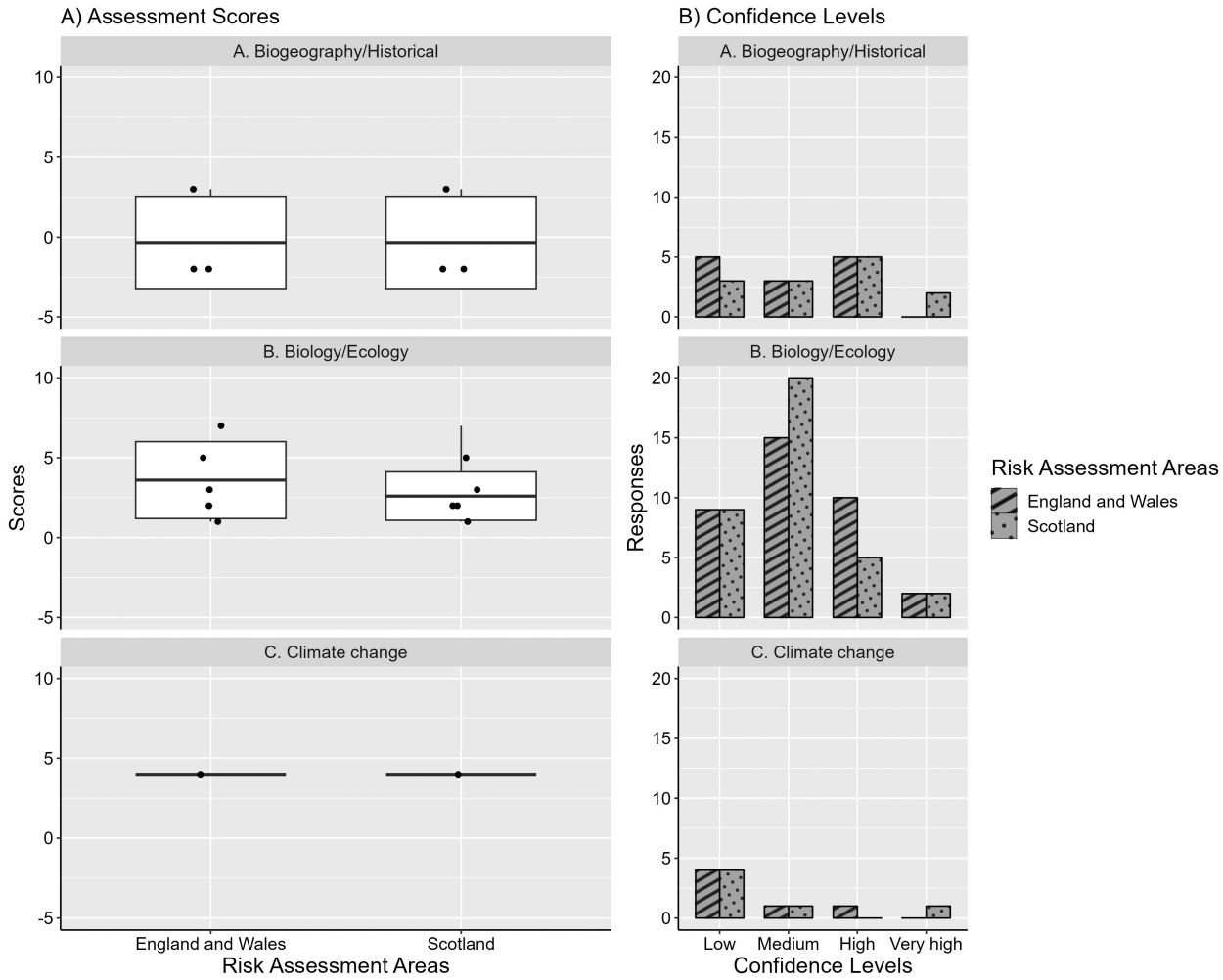

Figure 1. Summaries of the AS-ISK screening responses for both risk assessment areas. A) Boxplots of the scores by risk assessment section. B) Bar charts of the confidence levels for both risk assessment areas by questionnaire section

Risk screening

The risk assessment scores derived in this study place the shimofuri goby in a category of medium risk. This matches the results from a recent assessment for the naked goby, another estuarine species, in the North Sea (Dodd et al. 2022). In part, the medium score reflects a lack of definite impact in the areas where it has established non-native populations in China and the USA, and there is potential for its risk score to increase if impacts are found there in future. The species scores relatively highly in terms of its adaptability (particularly in terms of diet and tolerances to a range of temperatures and salinities), suggesting that establishment would be likely if the shimofuri goby were to arrive in GB waters. However, the shimofuri goby's generalist and adaptable nature makes the confident prediction of specific impacts difficult, due to a lack of information on its interactions with native taxa. This, along with limitations on available information on the species' ecology and behaviours within its native range, was highlighted with the generally medium to low confidence that the assessors assigned to question responses (Figure 1b).

The greatest distinction in the scores for the two RA areas was caused by differences in potential impacts on bullheads (*Cottus* spp.) which were identified as the most likely species to be directly affected by the shimofuri goby's introduction. Notwithstanding current debate on the taxonomy of bullhead populations in GB (e.g. Freyhoff et al. 2005; Fast et al. 2017; McLeish et al. 2020), their differing conservation status between the two RA areas results in varying policy and ecological relevance for any potential impacts which the shimofuri goby could exert on these populations, driving the difference in scores in this study (Figure 1b). In England & Wales, the bullhead is native and considered a species of conservation importance as a designated feature of a number of Special Areas of Conservation (Cowx et al. 2009). In Scotland, the species is not native and is designated as invasive due to a perceived threat to native species (Gaudin and Caillere 2000; Elliott 2006). Decline in bullhead abundance was observed in the Netherlands, after the establishment of several Ponto-Caspian goby species, most notably the round goby *Neogobius melanostomus* (Pallas, 1814) (van Kessel et al. 2016). As such, it was deemed likely that the shimolfuri goby would exert similar impacts on bullheads if it were introduced to the RA areas, which led to a divergence in the responses to question 26 in the two risk screenings (Tables S1, S2).

Dispersal mechanisms

The most likely potential mechanism for the shimofuri goby to arrive in both RAs was deemed to be via ballast water exchange, with a potential additional route of introduction as eggs attached to shells or solid material in dredging waste. Transport in ballast water was identified as the most likely route for the species' introduction to the USA (Matern 2001; Howard and Booth 2016), and the recent discovery of this species in a Belgian shipping canal (Verhelst and Verreycken 2023) lends further credence to this theory. Due to this factor, open-ocean ballast-water exchange has been suggested as a measure to limit the risk of introducing this species to new areas (Matern 2001).

Unaided dispersal to GB from Belgium or other undiscovered or future populations in continental Europe is unlikely as the species cannot tolerate true seawater salinities (Matern 2001). The shimofuri goby's dispersal within fresh and brackish water environments has been attributed to the passive dispersal of their planktonic larvae, which can be transported by water currents (Qin et al. 2023). This has notably taken place in the context of inter-basin water transfer projects (IBWT) in eastern China, where the goby's spread to new freshwater environments has been attributed to two IBWTs which involved the diversion of water from the lower reaches of the Yangtze River (Qin et al. 2023). These enabled the shimofuri goby to establish populations in several lakes and reservoirs throughout the region (Qin et al. 2020a, b; Qin et al. 2023). In a similar manner, the shimofuri goby's dispersal in various lakes and reservoirs throughout its non-native

North American range has been attributed to the California State Water Project (Howard and Booth 2016). Inter-basin water transfers are considered a high-risk pathway by which species may colonise new areas, as these create high propagule pressures, by regularly transporting large numbers of individuals to previously inaccessible catchments or regions (Qin et al. 2023). A number of current and planned IBWT projects exist within Great Britain, such as the Tyne-Tees Transfer (Khadem et al. 2021) and the planned River Severn to River Thames Transfer (Severn Trent Water 2021), which could provide the shimofuri goby with a means of dispersing to new river systems, if inlets were accessible to gobies in the lower reaches of rivers.

Establishment – climate factors

Both assessed areas were scored as being moderately similar to the shimofuri goby's native range, as indicated in question 4 of both risk assessments (Tables S1, S2). The adaptability of this species is demonstrated by its ability to thrive in a wide range of ambient temperatures. A study by Matern (2001) found the species' critical thermal maxima to be around 31°C to 34 °C when acclimated to 20 °C. This trait is believed to have aided in the shimofuri goby's establishment in California, by allowing it to tolerate highly variable conditions within the estuary, and to survive in small pools at low tide (Matern 2001). Despite a lack of specific information on the species' lower thermal limits, some information can be gleaned from its current native and non-native ranges. The shimofuri goby is native to areas which undergo drastic changes in temperature throughout the year. In Korea, Ye et al. (2014b) found the shimofuri goby to be the most abundant species in a tidal creek which experiences considerable temperature fluctuations over the course of the year, reaching temperatures of around 28 °C in the summer, and dropping to around 5 °C in the winter. Furthermore, the shimofuri goby appears to be able to adapt to lower temperatures in its non-native range in China. In particular, the shimofuri goby is present in Shuangwangcheng Reservoir where water temperatures reach an average minimum of 3.1 °C in January (Tang et al. 2018), and Nansi Lake which drops to an average of around 0 °C in January and February (Tian et al. 2012).

This information suggests that the shimofuri goby would be able to tolerate winter temperatures which it would encounter within Great Britain. Verhelst and Verreycken (2023) drew similar conclusions in their assessment for Belgium, when first reporting the discovery of this species in Europe. Furthermore, modelling work undertaken by Chen et al. (2024) indicated that a significant amount of suitable coastal habitat for the shimofuri goby, most notably in the form of "low-adaptive areas" and "moderate-growth areas" are present around Great Britain. The findings of this modelling work also indicate that the range of suitable habitats would increase under several Representative Concentration Pathway scenarios. However, it should be noted that Chen et al. (2024) makes a comprehensive assessment of

coastal habitats, but does not account for freshwater habitats, and as such only provides a partial view of the shimofuri goby's potential invasive range in Great Britain.

Establishment – other factors

In both RA areas, it was considered that the species' generalist and adaptable traits would facilitate its establishment, if introduced, as noted in questions 17, 23, 25, and 28 (Tables S1, S2). These traits include a broad diet (Ye et al. 2014a; Qin et al. 2020b), and tolerance of a wide range of environmental conditions (Matern 2001). The shimofuri goby predominantly feeds on benthic invertebrates, as well as other fish and their eggs (Matern and Brown 2005; Ye et al. 2014a; Qin et al. 2020b). In the San Francisco Bay, Matern and Brown (2005) found that a significant proportion of the shimofuri goby's diet was composed of two non-native invertebrate species which were not predated by native fishes. The exploitation of novel prey may limit the goby's direct impacts on native species in the San Francisco Estuary and may partly explain how the goby has proliferated in the area while other fish species have declined (Matern et al. 2002; Matern and Brown 2005).

The shimofuri goby inhabits brackish environments within its native range and possesses an upper salinity tolerance of 17% (Matern 2001). However, this species has successfully established itself in freshwater lakes and reservoirs in its introduced ranges of both China and the USA, where it has bred for multiple generations (Matern 2001; Qin et al. 2020a). This species would therefore likely be able to establish itself in a wide range of freshwater and brackish habitats within GB.

Finally, several attributes of this species' reproductive biology and behaviours have been suggested to assist its proliferation within new environments. These include high reproductive investment, parental nest guarding, and phenotypic plasticity in its life history traits (Qin et al. 2020a). Work undertaken by Qin et al. (2020a) indicated that individuals in Nansi Lake in China typically live for one year and adopted a single spawning strategy, in contrast to the species' life history in the San Francisco Estuary in the USA, where individuals live for two years and spawn in multiple batches throughout an extended reproductive season from March to August. These contrasting strategies are believed to best suit surrounding environmental conditions, with the more variable conditions of the San Francisco Estuary making batch spawning within a longer reproductive season more advantageous (Hočevar et al. 2021), while the relatively stable conditions of lakes and reservoirs would make the high energetic cost of multiple batch-spawning inefficient (Qin et al. 2020a). Studies undertaken in Nansi Lake in China also revealed that males of this species exhibit parental care and nest-guarding behaviours after spawning, further assisted by male-biased sexual size dimorphism and sex ratios (Qin et al. 2020a). The ability to adapt life-history traits in this manner is believed to offer certain fish species a

considerable advantage when establishing themselves in new areas (Fox and Copp 2014).

Potential impacts in GB

During the risk screening process, little direct evidence could be found for impacts on biodiversity or ecosystems in its non-native range, although there are potential impacts which have not been definitively proven. In both areas outside its native range where the goby has become established, its arrival was followed by a decline in the abundance of native fishes (Meng et al. 1994; Qin et al. 2020b), although direct causation cannot be proved. Additionally, through behavioural studies, Matern (1999) found that the shimofuri goby displayed aggressive behaviours towards ecologically similar native gobies in the San Francisco Estuary, and concluded that the goby's invasion to the area could pose a risk to the endangered tidewater goby *Eucyclogobius newberryi* (Girard, 1856). In addition, laboratory studies showed that the shimofuri goby outcompeted the non-native Harris mud crab *Rhithropanopeus harrisii* (Gould, 1841) for shelter, especially during the day and in the spawning season (Matern 2001).

The shimofuri goby's propensity to feed on small fish and fish eggs, along with its tendency to display territorial aggression towards other species, suggest that this species' introduction could lead to deleterious effects for a wide range of native fishes. As a whole, it was deemed that the shimofuri goby's introduction would most likely impact on similarly-sized or smaller brackish and freshwater fishes through competition and predation, with the most likely impacted taxa being bullhead. As a predator of fish eggs expected to occupy a similar niche to bullheads, shimofuri goby has the potential to exert similar negative effects on salmonid recruitment, at least at a local level, as have been recorded for bullheads (Palm et al. 2009). Another species of conservation concern in both RA areas which might be expected to be subject to egg predation by the shimofuri goby is the European smelt *Osmerus eperlanus* (Linnaeus, 1758), which generally spawns in the lower reaches of rivers, and deposit their eggs onto available substrates (Quigley et al. 2004). However, a lack of information on the interactions between the shimofuri goby and native taxa to the RA areas makes the accuracy of these predictions uncertain.

Future directions

Non-native species risk analyses are a vital conservation tool, as they serve to underpin management strategies for species likely to be introduced, and those which could have significant impacts on native taxa (Lodge et al. 2016). The development of electronic decision-support tools in recent years has improved the quality and efficiency of such analyses (Copp et al. 2016), which in turn has improved the efficacy of management efforts (Vilizzi et al. 2021). As such, these tools are now seen as essential for the development of effective policies and management strategies for non-native species (Copp

et al. 2016). Indeed, freshwaters are regarded as possibly the most widely threatened ecosystem worldwide (Carpenter et al. 2011; Taybi et al. 2020), and the position of estuaries at the interface between freshwater and marine environments make them vulnerable to introduction vectors from both environments (Padilla and Williams 2004; Gertzen et al. 2008; Bailey 2015). As such, monitoring potential threats to these environments, and continuing to develop effective detection and management methods is of vital importance (Crall et al. 2011; Thomas et al. 2020).

The recent report of shimofuri goby from Terneuzen shipping canal in Belgium (Verhelst and Verreycken 2023) was insufficient to conclude whether the species has successfully established itself in the area, highlighting the need for further investigations. The authors noted that the small size of the species and relative similarity to other goby species may have allowed a small population of shimofuri gobies to survive in the canal undetected. In the UK, there is little monitoring targeted at non-native fishes, particularly in brackish water. The continued monitoring of potential introduction routes, especially around estuarine shipping ports using environmental DNA surveying which has proven successful for detecting invasive gobies (Adrian-Kalchhauser et al. 2016; Nevers et al. 2018), combined with raising awareness of the species' potential arrival with anglers and other stakeholders, is likely the best means to increase likelihood of detection.

Author's contribution

GHC conceptualised the study. LP and JAD conducted the risk assessments, which were reviewed by PID. LP drafted the manuscript. All authors contributed edits to subsequent drafts of the manuscript.

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References

Adrian-Kalchhauser I, Burkhardt-Holm P (2016) An eDNA assay to monitor a globally invasive fish species from flowing freshwater. *PLoS ONE* 11: e0147558, https://doi.org/10.1371/journal.pone.0147558

Bailey SA (2015) An overview of thirty years of research on ballast water as a vector for aquatic invasive species to freshwater and marine environments. *Aquatic Ecosystem Health & Management* 18: 261–268, https://doi.org/10.1080/14634988.2015.1027129

Britton JR (2023) Contemporary perspectives on the ecological impacts of invasive freshwater fishes. *Journal of Fish Biology* 103: 752–764, https://doi.org/10.1111/jfb.15240

Britton JR, Copp GH, Brazier M, Davies GD (2011) A modular assessment tool for managing introduced fishes according to risks of species and their populations, and impacts of management actions. *Biological Invasions* 13: 2847–2860, https://doi.org/10.1007/s10530-011-9967-0

Carpenter SR, Stanley EH, Vander Zanden MJ (2011) State of the world's freshwater ecosystems: physical, chemical, and biological changes. *Annual Review of Environment and Resources* 36, 75–99, https://doi.org/10.1146/annurev-environ-021810-094524

Chen S, Xiao Y, Xiao Z, Ma D, Li J, Herrera-Ulloa A (2024) Prediction of suitable habitat shifts and assessment of ecological niche overlaps for three *Tridentiger* species with intertidal and subtidal characteristics under future climate changes. *Marine Pollution Bulletin* 198: 115827, https://doi.org/10.1016/j.marpolbul.2023.115827

Copp GH, Vilizzi L, Tidbury H, Stebbing PD, Tarkan AS, Miossec L, Goulletquer P (2016) Development of a generic decision-support tool for identifying potentially invasive aquatic taxa: AS-ISK. *Management of Biological Invasions* 7: 343–350, https://doi.org/10.3391/mbi.2016.7.4.04

Copp GH, Wesley KJ, Verreycken H, Russell IC (2007) When an 'invasive' fish species fails to invade! Example of the topmouth gudgeon *Pseudorasbora parva*. *Aquatic Invasions* 2: 107–112, https://doi.org/10.3391/ai.2007.2.2.4

Cowx IG, Harvey JP, Noble RA, Nunn AD (2009) Establishing survey and monitoring protocols for the assessment of conservation status of fish populations in river Special Areas of Conservation in the UK. Aquatic Conservation: *Marine and Freshwater Ecosystems* 19: 96–103, https://doi.org/10.1002/aqc.968

Crall AW, Renz M, Panke B, Newman GJ (2011) Is there a role for the public in monitoring invasive species? *CABI Reviews* 6: 023, https://doi.org/10.1079/PAVSNNR20116023

Dodd JA, Copp GH, Tidbury HJ, Leuven RS, Feunteun E, Olsson KH, Gollasch S, Jelmert A, O'Shaughnessy KA, Reeves D, Brenner J, Verreycken H (2022) Invasiveness risks of naked goby, *Gobiosoma bosc*, to North Sea transitional waters. *Marine Pollution Bulletin* 181: 113763, https://doi.org/10.1016/j.marpolbul.2022.113763

Dodd JA, Vilizzi L, Bean CW, Davison PI, Copp GH (2019) At what spatial scale should risk screenings of translocated freshwater fishes be undertaken-River basin district or climo-geographic designation? *Biological Conservation* 230: 122–130, https://doi.org/10.1016/j.biocon.2018.12.002

Elliott JM (2006) Periodic habitat loss alters the competitive coexistence between brown trout and bullheads in a small stream over 34 years. *Journal of Animal Ecology* 75: 54–63, https://doi.org/10.1111/j.1365-2656.2005.01022.x

Fabrizio MC, Nepal V, Tuckey TD (2021) Invasive blue catfish in the Chesapeake Bay region: a case study of competing management objectives. *North American Journal of Fisheries Management* 41: S156–S166, https://doi.org/10.1002/nafm.10552

Fast K, Aguilar A, Nolte AW, Sandel MW (2017) Complete mitochondrial genomes for *Cottus asper*, *Cottus perifretum*, and *Cottus rhenanus* (Perciformes, Cottidae). *Mitochondrial DNA Part B*. 2: 666–8, https://doi.org/10.1080/23802359.2017.1375870

Fox MG, Copp GH (2014) Old world versus new world: life-history alterations in a successful invader introduced across Europe. *Oecologia* 174: 435–446, https://doi.org/10.1007/s00442-013-2776-7

Freyhof J, Kottelat M, Nolte A (2005) Taxonomic diversity of European *Cottus* with description of eight new species (Teleostei: Cottidae). *Ichthyological Exploration of Freshwaters* 16: 107–172

Gaudin P, Caillere L (2000) Experimental study of the influence of presence and predation by sculpin, *Cottus gobio* L., on the drift of emergent brown trout, *Salmo trutta* L. *Archiv fuer Hydrobiologie*. 147: 257–271, https://doi.org/10.1127/archiv-hydrobiol/147/2000/257

Gertzen E, Familiar O, Leung B (2008) Quantifying invasion pathways: fish introductions from the aquarium trade. *Canadian Journal of Fisheries and Aquatic Sciences* 65: 1265–1273, https://doi.org/10.1139/F08-056

Glamuzina B, Tutman P, Glamuzina L, Vidović Z, Simonović P, Vilizzi L (2021) Quantifying current and future risks of invasiveness of non-native aquatic species in highly urbanised estuarine ecosystems - A case study of the River Neretva Estuary (Eastern Adriatic Sea: Croatia and Bosnia-Herzegovina). *Fisheries Management and Ecology* 28: 138–146, https://doi.org/10.1111/fme.12463

Hočevar S, Hutchings JA, Kuparinen A (2021) Multiple-batch spawning as a bet-hedging strategy in highly stochastic environments: An exploratory analysis of Atlantic cod. *Evolutionary Applications* 14: 1980–1992, https://doi.org/10.1111/eva.13251

Howard SR, Booth MT (2016) Range expansion of the shimofuri goby (*Tridentiger bifasciatus*) in southern California, with emphasis on the Santa Clara River. *California Fish and Game* 102(2): 45–49

Katsanevakis S, Zaiko A, Olenin S, Costello MJ, Gallardo B, Tricarico E, Adriaens T, Jeschke JM, Sini M, Burke N, Ellinas K, Rutten S, Poursanidis D, Marchini A, Brys R, Raeymaekers JAM, Noé N, Hermoso V, Blaalid R, Lucy FE, Verbrugge LNH, Staehr PAU, Vandepitte L, de Groot D, Elliott M, Reuver M, Maclaren J, Li M, Oldoni D, Mazaris A, Trygonis V, Hablützel PI, Everts T, Pistevos JCA, Dekeyzer S, Kimmig SE, Rickowski FS, Panov VE (2024) GuardIAS – Guarding European Waters from Invasive Alien Species. *Management of Biological Invasions* 15(4): 701–730, https://doi.org/10.3391/mbi.2024.15.4.14

Khadem M, Dawson RJ, Walsh CL (2021) The feasibility of inter-basin water transfers to manage climate risk in England. *Climate Risk Management* 33: 100322, https://doi.org/10.1016/j.crm.2021.100322

Lodge DM, Simonin PW, Burgiel SW, Keller RP, Bossenbroek JM, Jerde CL, Kramer AM, Rutherford ES, Barnes MA, Wittmann ME, Chadderton WL, et al. (2016) Risk analysis and

bioeconomics of invasive species to inform policy and management. *Annual Review of Environment and Resources* 41: 453–488, https://doi.org/10.1146/annurev-environ-110615-085532

Makarewicz JC, Lewis TW, Makarewicz JA (2016) Invasive species induced food web disruption, alternative regimes, and cyanobacteria dominance in a pelagic food web: a case history. *Inland Waters* 6: 35–53, https://doi.org/10.5268/IW-6.1.896

Marsico T, Burt J, Espeland E (2010) Underutilized resources for studying the evolution of invasive species during their introduction, establishment, and lag phases. *Evolutionary Applications* 3: 203–219, https://doi.org/10.1111/j.1752-4571.2009.00101.x

Matern SA (1999) The invasion of the shimofuri goby (*Tridentiger bifasciatus*) into California: establishment, potential for spread, and likely effects. PhD Thesis, University of California, Davis, 167 pp

Matern SA (2001) Using temperature and salinity tolerances to predict the success of the shimofuri goby, a recent invader into California. *Transactions of the American Fisheries Society* 130: 592–599, https://doi.org/10.1577/1548-8659(2001)130<0592:UTASTT>2.0.CO;2

Matern SA, Brown LR (2005) Invaders eating invaders: exploitation of novel alien prey by the alien shimofuri goby in the San Francisco Estuary, California. *Biological Invasions* 7: 497–507, https://doi.org/10.1007/s10530-004-6348-y

Matern SA, Moyle PB, Pierce LC (2002) Native and alien fishes in a California estuarine marsh: twenty-one years of changing assemblages. *Transactions of the American Fisheries Society* 131, 797–816, https://doi.org/10.1577/1548-8659(2002)131<0797:NAAFIA>2.0.CO;2

McLeish J, Briers RA, Dodd JA, Rueckert S (2020) First genetic evidence that invasive bullhead (*Cottus* L. 1758) in Scotland is of English origin and the difficulty of resolving the European *Cottus* species taxonomy. *Journal of Fish Biology* 96: 617–630, https://doi.org/10.1111/jfb.14247

Meng L, Moyle PB, Herbold B (1994) Changes in abundance and distribution of native and introduced fishes of Suisun Marsh. *Transactions of the American Fisheries Society* 123: 498–507, https://doi.org/10.1577/1548-8659(1994)123<0498:CIAADO>2.3.CO;2

Nevers MB, Byappanahalli MN, Morris CC, Shively D, Przybyla-Kelly K, Spoljaric AM, Dickey J, Roseman EF (2018) Environmental DNA (eDNA): A tool for quantifying the abundant but elusive round goby (*Neogobius melanostomus*). *PloS One* 13: e0191720, https://doi.org/10.1371/journal.pone.0191720

Padilla DK, Williams SL (2004) Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems. *Frontiers in Ecology and the Environment* 2: 131–138, https://doi.org/10.1890/1540-9295(2004)002[0131:BBWAAO]2.0.CO;2

Pagnucco KS, Remmal Y, Ricciardi A (2016) An invasive benthic fish magnifies trophic cascades and alters pelagic communities in an experimental freshwater system. *Freshwater Science* 35: 654–665, https://doi.org/10.1086/685285

Palm D, Lindberg M, Brännäs E, Lundqvist H, Östergren J, Carlsson U (2009) Influence of European sculpin, *Cottus gobio*, on Atlantic salmon *Salmo salar*, recruitment and the effect of gravel size on egg predation-implications for spawning habitat restoration. *Fisheries Management and Ecology* 16: 501–507, https://doi.org/10.1111/j.1365-2400.2009.00705.x

Peel MC, Finlayson BL, McMahon TA (2007) Updated world map of the Köppen-Geiger climate classification. *Hydrology and earth system sciences* 11: 1633–1644, https://doi.org/10.5194/hess-11-1633-2007

Qin J, Schmidt BV, Zhang L, Cheng F, Xie S (2023) Water transfer determines the regional spread dynamics of non-native fish species. *Water Biology and Security* 2: 100135, https://doi.org/10.1016/j.watbs.2023.100135

Qin J, Xiang M, Jia M, Cheng F, Schmidt BV, Liu J, Xie S (2020a) Combined opportunistic and equilibrium life-history traits facilitate successful invasions of the shimofuri goby (*Tridentiger bifasciatus*). *Aquatic Invasions* 15: 514–528, https://doi.org/10.3391/ai.2020.15.3.10

Qin J, Xie S, Cheng F (2020b) Broad diet composition and seasonal feeding variation facilitate successful invasion of the shimofuri goby (*Tridentiger bifasciatus*) in a water transfer system. *Water* 12: 3411, https://doi.org/10.3390/w12123411

Quigley DT, Igoe F, O'Connor W (2004) The European Smelt *Osmerus eperlanus* L. in Ireland: general biology, ecology, distribution and status with conservation recommendations. *Biology and Environment: Proceedings of the Royal Irish Academy*. 57–66, https://doi.org/10.1353/bae.2004.0027

Severn Trent Water (2021) River Severn to River Thames Transfer (STT) Strategic regional water resource solution Gate 1 submission. 40 pp. Available at: https://www.severntrent.com/content/dam/stw-plc/about-us/gate-1-submission-stt.pdf.

Tang W, Chu PP, Liang MY, Han YC (2018) Study on water transfer during ice period using the deep waters temperature of Shuangwangcheng Reservoir. IOP Conference Series: *Materials Science and Engineering* 392: 042013, https://doi.org/10.1088/1757-899X/392/4/042013

Taybi AF, Mabrouki Y, Villarejo ID (2020) The occurrence, distribution and biology of invasive fish species in fresh and brackish water bodies of NE Morocco. *Arxius de Miscel·lània Zoològica* 18: 59–73, https://doi.org/10.32800/amz.2020.18.0059

Thomas AC, Tank S, Nguyen PL, Ponce J, Sinnesael M, Goldberg CS (2020) A system for rapid eDNA detection of aquatic invasive species. *Environmental DNA* 2: 261–270, https://doi.org/10.1002/edn3.25

Tian C, Pei H, Hu W, Xie J (2012) Variation of cyanobacteria with different environmental conditions in Nansi Lake, China. *Journal of Environmental Sciences* 24: 1394–1402, https://doi.org/10.1016/S1001-0742(11)60964-9

van Kessel N, Dorenbosch M, Kranenbarg J, van der Velde G, Leuven RS (2016) Invasive Ponto-Caspian gobies rapidly reduce the abundance of protected native bullhead. *Aquatic Invasions* 11: 179–188, https://doi.org/10.3391/ai.2016.11.2.07

Verhelst P, Verreycken H (2023) First record in Europe of the Asian gobiid, shimofuri (marbled) goby *Tridentiger bifasciatus* Steindachner, 1881. *Journal of Fish Biology* 102: 1253–1255, https://doi.org/10.1111/jfb.15362

Vilizzi L, Copp GH, Hill JE, Adamovich B, Aislabie L, Akin D, Al-Faisal AJ, Almeida D, Azmai MA, Bakiu R, Bellati A, Bernier R, Miles JM, Bilge G, Branco P, Bui TD, Canning-Clode J, Anatole Cardoso Ramos H, Castellanos-Galindo GA, Castro N, Chaichana R, Chainho P, Chan J, Cunico AM, Curd A, Punyanuch Dangchana P, Dashinov, Davison PI, de Camargo MP, Dodd JA, Durland Donahou AL, Edsman L, Ekmekçi FG, Elphinstone-Davis J, Erős T, Evangelista C, Fenwick G, Ferincz Á, Ferreira T, Feunteun E, Filiz H, Forneck SC, Gajduchenko HS, Gama Monteiro J, Gestoso I, Giannetto D, Gilles Jr AS, Gizzi F, Glamuzina B, Glamuzina L, Goldsmit J, Gollasch S, Goulletquer P, Grabowska J, Harmer R, Haubrock PJ, He D, Hean JW, Herczeg G, Howland KL, İlhan A, Interesova E, Jakubčinová K, Jelmert A, Johnsen SI, Kakareko T, Kanongdate K, Killi N, Kim JE, Kırankaya ŞG, Kňazovická D, Kopecký O, Kostov V, Koutsikos N, Kozic S, Kuljanishvili T, Kumar B, Kumar L, Kurita Y, Kurtul I, Lazzaro L, Lee L, Lehtiniemi M, Leonardi G, Leuven RSEW, Li S, Lipinskaya T, Liu F, Lloyd L, Lorenzoni M, Luna SA, Lyons TJ, Magellan K, Malmstrøm M, Marchini A, Marr SM, Masson G, Masson L, McKenzie CH, Memedemin D, Mendoza R, Minchin D, Miossec L, Moghaddas SD, Moshobane MC, Mumladze L, Naddafi R, Najafi-Majd E, Năstase A, Năvodaru I, Neal JW, Nienhuis S, Nimtim M, Nolan ET, Occhipinti-Ambrogi A, Ojaveer H, Olenin S, Olsson K, Onikura N, O'Shaughnessy K, Paganelli D, Parretti P, Patoka J, Pavia Jr RTB, Pellitteri-Rosa D, Pelletier-Rousseau M, Peralta EM, Perdikaris C, Pietraszewski D, Piria M, Pitois S, Pompei L, Poulet N, Preda C, Puntila-Dodd R, Qashqaei AT, Radočaj T, Rahmani H, Raj S, Reeves D, Ristovska M, Rizevsky V, Robertson DR, Robertson P, Ruykys L, Saba AO, Santos JM, Sarı HM, Segurado P, Semenchenko V, Senanan W, Simard N, Simonović P, Skóra ME, Slovák Švolíková K, Smeti E, Šmídová T, Špelić I, Srėbalienė G, Stasolla G, Stebbing P, Ševove B, Suresh VR, Szajbert B, Ta KAT, Tarkan AS, Jonathan Tempesti J, Therriault TW, Hannah J. Tidbury HJ, Top-Karakuş N, Elena Tricarico E, Troca DFA, Tsiamis KM, Tuckett QM, Pero Tutman P, Uyan U, Uzunova E, Vardakas L, Velle G, Verreycken H, Lizaveta Vintsek L, Wei H, Weiperth A, Weyl OLF, Winter ER, Włodarczyk R, Wood LE, Yang R, Yapıcı S, Yeo SSB, Yoğurtçuoğlu B, Yunnie ALE, Zhu Y, Zięba G, Žitňanová K, Clarke S (2021) A global-scale screening of non-native aquatic organisms to identify potentially invasive species under current and future climate conditions. *Science of the Total Environment* 788: 147868, https://doi.org/10.1016/j.scitotenv.2021.147868

Vilizzi L, Piria M, Copp GH (2022) Which calibrated threshold is appropriate for ranking non-native species using scores generated by WRA-type screening toolkits that assess risks under both current and future climate conditions. *Management of Biological Invasions* 13: 593608, https://doi.org/10.3391/mbi.2022.13.4.01

Ye SJ, Jeong JM, Kim HJ, Park JM, Huh SH, Baeck GW (2014a) Feeding habits of *Tridentiger bifasciatus* in the tidal creek at Sangnae-ri, Suncheon, Korea. *Korean Journal of Fisheries and Aquatic Sciences* 47: 160–167, https://doi.org/10.5657/KFAS.2014.0160

Ye SJ, Jeong JM, Kim HJ, Park JM, Huh SH, Baeck GW (2014b) Fish assemblage in the tidal creek of Sangnae-ri Suncheon, Korea. *Korean Journal of Ichthyology* 26(1): 74–80

Zenni RD, Nuñez MA (2013) The elephant in the room: the role of failed invasions in understanding invasion biology. *Oikos* 122: 801815, https://doi.org/10.1111/j.1600-0706.2012.00254.x

Websites, online databases and software

Australian Bureau of Rural Sciences (2020) Climatch. https://climatch.cp1.agriculture.gov.au/climatch.jsp (accessed 22 February 2023)

Supplementary material

The following supplementary material is available for this article:

Table S1. Risk assessment questionnaire and summary statistics for the shimofuri goby in England and Wales
Table S2. Risk assessment questionnaire and summary statistics for the shimofuri goby in Scotland

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