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Asian Loaches: An Emerging Threat as Global Invaders

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ABSTRACT

1. The introduction of non-native species is a major driver of biodiversity loss, posing a growing threat to the health and functioning of freshwater ecosystems globally. In recent decades, pet trade and aquarophilia have become lucrative industries, accelerating the introduction and spread of new non-native fishes. This includes several Asian loach species that have recently been detected outside their native range, such as in Europe, the United States and Australia. Here, we examine the potential of the large-scale loach *Paramisgurnus dabryanus* and the dojo weatherloach *Misgurnus anguillicaudatus* to establish outside their native range, and address potential impacts on the threatened European weatherfish *Misgurnus fossilis*.
2. We used species distribution models (SDM) to estimate the potential global environmental suitability for both Asian loach species and identified key variables determining current distributions.
3. Our results indicate that both species could spread globally and become invasive, with *M. anguillicaudatus* appearing more capable of larger range expansions compared to *P. dabryanus*. Especially temperate regions of Europe, North and South America, the south-eastern coast of Australia, and Asia were identified as the most vulnerable areas. Range expansions of both studied Asian loaches in Europe could lead to an increased distribution overlap with populations of the native *M. fossilis*, with projections showing *P. dabryanus* increasing from a current overlap of 0.1% to 4.1% and *M. anguillicaudatus* from 0.2% to 32.8%.
4. Our findings indicate that the introduction of non-native loaches may pose a substantial threat to *M. fossilis* in its native range, but also to other native species, especially benthic fish and macroinvertebrate species. Preventing new introductions and targeted research on the ecology and distribution patterns of such highly invasive species with growing presence in the international pet trade is essential to halt their further spread. SDMs can offer relevant spatial data for policymakers by identifying regions vulnerable to invasions and prioritising areas for targeted surveillance and management efforts.

1 | Introduction

The introduction of non-native species poses a significant threat to global biodiversity, driven by various impacts such as competition for resources, predation, hybridization, disease transmission, behavioural disruption and habitat alteration, among others (Simberloff et al. 2013; Gallardo et al. 2016; Soto et al. 2024). Past species introductions have entailed annual economic costs of billions of dollars worldwide (Diagne et al. 2020). Although the awareness for biological invasions has increased over the last decades, even resulting in new legislations (Genovesi et al. 2015), rates of introductions do not show any sign of saturation (Seebens et al. 2017). This indicates that currently enacted measures to mitigate new introductions have not been effective (e.g., Dimitriadis et al. 2024; Santis et al. 2024). Moreover, the globalisation of trade and travel networks has resulted in the creation of new and continuously shifting introduction pathways (Clavero et al. 2023), further exacerbating the unpredictable nature of introduced non-native species spreading. In the last decades, especially the international pet trade has become a lucrative business and is considered one of the main pathways for the introduction of non-native species (Early et al. 2016). This is because new species that possess novel or appealing features that distinguish them from previously sold species and native species continuously enter the pet market (see Novel Weapons Theory; Callaway and Ridenour 2004) while their abundant presence (i.e., propagule pressure; Briski et al. 2014) increases the chances of establishment and spread (Levine and D'Antonio 2003; Gippet and Bertelsmeier 2021; Clavero et al. 2023).

In freshwater ecosystems worldwide, more than 550 non-native fish species have successfully established self-sustaining populations outside their native range, being recognised as a major driver of freshwater biodiversity loss (Su et al. 2021; Bernery et al. 2022). Asian loaches of the genus *Paramisgurnus* and *Misgurnus* are currently among the most commonly introduced fishes in Europe and North America (Clavero et al. 2023). They are economically relevant species extensively cultured in East-Asian countries including China, Korea, and Japan (Zhang et al. 2021), and are regularly exported as ornamental species for garden ponds and aquariums, as well as live bait (Kottelat and Freyhof 2007). More specifically, the large-scale loach *Paramisgurnus dabryanus* Dabry de Thiersant, 1872, native to the Yangtze and Pearl drainages in China and to inland waters of Taiwan (Kottelat and Freyhof 2007), has recently been introduced and established self-sustaining populations in the United States (Kirsch et al. 2018), Spain (Clavero et al. 2023), Germany (Stoeckle 2019) and Japan (Kanou et al. 2007). Similarly, the dojo weatherloach *Misgurnus anguillicaudatus* (Cantor, 1842) native to the temperate zones of East Asia, ranging from southern Siberia to northern Vietnam, including Sakhalin, Korea and Japan (Stoeckle 2019), has been widely introduced in Europe, south-eastern Australia, and in the eastern and western coasts of the United States (Keller and Lake 2007). It is, however, likely that particularly those loaches from the genus *Misgurnus* and *Paramisgurnus* have a broader distribution range than currently recognised due to the challenges in accurately identifying these species (see e.g., Zangl et al. 2020). In fact, *P. dabryanus* and *M. anguillicaudatus* can live in sympatry and are often exported in mixed batches, which could enable both species to establish in areas invaded by either (Freyhof 2013).

Although the full extent of the invasiveness and impacts of *P. dabryanus* and *M. anguillicaudatus* is not yet completely understood (Cuinet et al. 2024), previous studies revealed negative effects of these species on native benthic organisms (Hazelton and Grossman 2009). This is especially true when these loaches establish high densities, which is largely due to their high reproductive capacity (Chu et al. 2012) and their omnivorous, bottom-feeding habits (Kanou et al. 2007), which can disrupt local ecosystems. Moreover, it is known that *P. dabryanus* and species of the genus *Misgurnus* can hybridise in natural conditions (You et al. 2009; Wanzenböck et al. 2021). It is therefore likely that introduced populations of *P. dabryanus* and *M. anguillicaudatus* become a threat for populations of other endemic loach species in Asia, and for the European weatherfish *Misgurnus fossilis*, which is a widespread loach native to Europe and some parts of Asia. It occurs north of the Alps, from the Meuse River in France and Belgium, to the Neva River in Russia. It is also present in the Black Sea basin from the Danube to the Kuban River, and in the Caspian Sea basin in the Volga and Ural drainages. *Misgurnus fossilis* is considered to be of high conservation concern because of their declining populations (Freyhof 2013; IUCN 2024). It is listed in Appendix III of the Bern Convention and Annex II of the European Union Habitats Directive, highlighting the urgent need for conservation efforts to protect this species and its habitats (Hartvich et al. 2010; Stoeckle 2019; IUCN 2024).

Species distribution models (SDMs) have been established as a useful tool by invasion scientists to identify the distribution of non-native species, to predict areas at risk, to optimise control strategies and decision making, and to examine potential impacts on native biodiversity (Guisan et al. 2013; Tulloch et al. 2014; Gallardo et al. 2017; Tingley et al. 2018). In fact, SDMs have become a well-established tool for conservation purposes as well (Bazzichetto et al. 2018) because of the increasing availability of spatial data in open databases (see e.g., GBIF) and the development of remote sensing (Franklin 2013; He et al. 2015). Hence, by using SDMs, we aim to (1) assess the importance of different climatic, topographic, and anthropogenic factors in shaping the current distribution of *P. dabryanus* and *M. anguillicaudatus*, (2) analyse their range expansion potential worldwide and (3) explore possible impacts of *P. dabryanus* and *M. anguillicaudatus* on threatened populations of *M. fossilis* in Europe. We hypothesise that both Asian loach species will exhibit broad environmental and climatic tolerances and thus high potential for a future spread. We anticipate that *P. dabryanus* and *M. anguillicaudatus* could successfully colonise and establish in new regions across Europe, potentially posing significant threats to native populations of *M. fossilis*.

2 | Methods

2.1 | Occurrence Data

Occurrences of *P. dabryanus* and *M. anguillicaudatus* were obtained from the Global Biodiversity Information Facility (GBIF; GBIF.org 2023b, 2024a), the Freshwater Biodiversity Data Portal (BioFresh 2023), and 10 additional sources, including research articles and other public databases (see Table S1). We excluded records of animals housed in zoos or aquariums, as they may not accurately reflect the species' natural distribution. The spatial resolution of species occurrences was set to 0.5° to standardise the resolutions across data sources. A resolution of 0.5° is commonly used in globally conducted ecological studies (e.g., Bellard et al. 2013) and fish atlases containing occurrence data (e.g., Doadrio 2001). The final dataset was manually verified and cleaned by removing duplicated or redundant records within a grid cell and observations located in the sea. A total of 88 unique records in 9 countries were retrieved for *P. dabryanus*, and 335 unique records in 17 countries for *M. anguillicaudatus* (see Figure 1a,b). To investigate overlap in Europe between the two non-native species *P. dabryanus* and *M. anguillicaudatus*

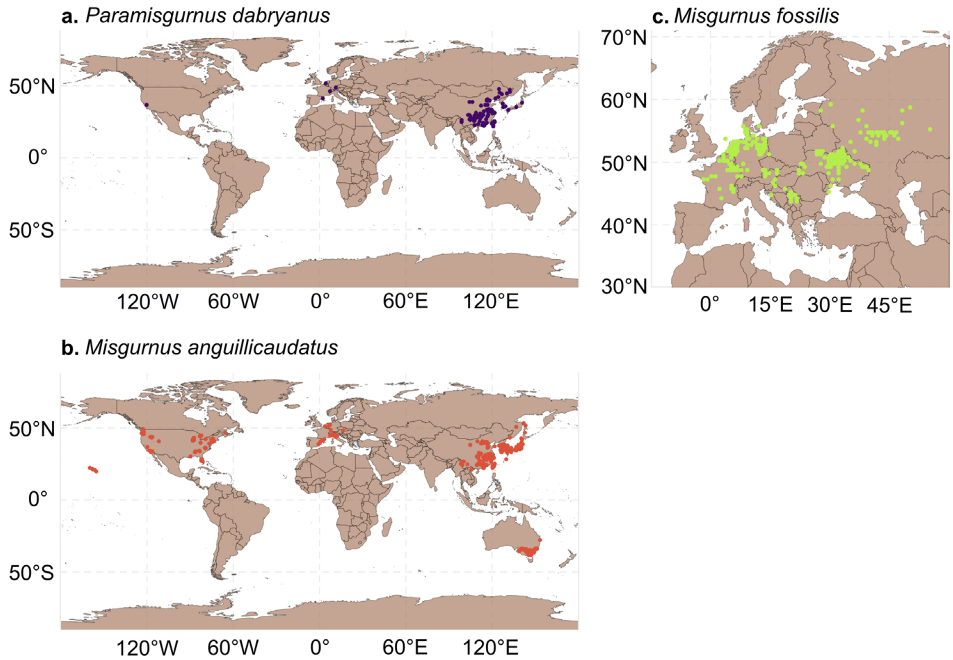

FIGURE 1 | Distribution of (a) *Paramisgurnus dabryanus*, (b) *Misgurnus anguillicaudatus* and (c) *Misgurnus fossilis*.

with the native European weatherfish *M. fossilis*, 212 occurrences of *M. fossilis* in its native region were obtained from GBIF (GBIF.org 2024b) (Figure 1c).

2.2 | Environmental Data

We initially collected 25 climatic, topographic and anthropogenic variables (see Table S2 for complete list of predictor variables) from various open sources commonly used in species distribution modelling including the WorldClim and Global Dam Tracker databases (Fick and Hijmans 2017; Zhang and Gu 2023), as well as the 'sdmpredictors' and 'geodata' R packages (Bosch and Fernandez 2016; Hijmans et al. 2024). We rescaled all variables to a modelling grid with a resolution of 0.5° to agree with the grain of occurrence data by calculating the mean values of the cells from the original layer with a higher resolution. Strongly correlated variables with Pearson correlation coefficients $|r| \geq 0.7$ were removed in order to reduce multicollinearity (Figure S1). Nine predictor variables were finally selected based on their ecological relevance and previous studies highlighting their importance in modelling freshwater fish distributions (see Table S3 for further details) (Radinger et al. 2019; Cano-Barbacil et al. 2022). The selected climatic variables were annual mean temperature and temperature annual range, which are key drivers of species distributions (Cano-Barbacil et al. 2022); precipitation seasonality, precipitation of wettest quarter and precipitation of driest quarter, which provide information on the water seasonal availability (Fick and Hijmans 2017); and the Thornthwaite aridity index (Bosch and Fernandez 2016). As topographic variable, we selected elevation because higher altitudes are typically associated with steeper habitats, faster flowing waters, reduced occurrences of side-channel habitats and lower water temperatures (Jarvis et al. 2008; Murphy et al. 2015). As anthropogenic variables we used human footprint as proxy for propagule pressure of non-native species (Gallardo et al. 2015; Venter et al. 2016); and number of dams as an indicator of the direct influence of reservoirs (Zhang and Gu 2023).

2.3 | Species Distribution Models and Analysis

We used the BIOMOD computational framework, as implemented in the R-package 'biomod2' (Thuiller et al. 2009, 2024), to model the global distribution of the Asian loaches *P. dabryanus* and *M. anguillicaudatus*. We used four complementary and widely used algorithms to compute individual models: generalised linear models (GLM), generalised boosting models (GBM), random forests (RF) and maximum entropy (Maxent) (Bellard et al. 2013; Cano-Barbacil et al. 2022). To develop species-specific SDMs, we only considered occurrences within a species' native range, excluding those from non-native areas, which are typically driven by human decisions, particularly during the early stages of invasion. For each species, we generated three sets of 1000 informed pseudo-absences from a larger set of background points since our datasets did not include reliable absence locations (Chapman et al. 2019). Specifically, as potential background region, we considered only areas that have been sampled for Cypriniformes (i.e., cells with Cypriniformes records in GBIF) but excluding sites with occurrence records of the modelled target species. The models were calibrated 10 times using 70% of randomly selected occurrence data and were validated on the remaining 30%. We evaluated the model's predictive accuracy using four complementary metrics: the area under the receiver operating characteristic curve (AUC), the true skill statistic (TSS), sensitivity, and specificity. The ensemble forecast was computed based on individual models with an AUC > 0.7, and weighted by their AUC in order to obtain more robust predictions (Marmion et al. 2009; Cano-Barbacil et al. 2022).

We assessed the importance of each predictor variable (hereafter referred to as 'variable importance') for each modelled species to identify key factors influencing their current distribution. For assessing variable importance we used the internal procedure of 'biomod2', which applies Pearson correlation between the fitted values (i.e., standard predictions) and predictions where the selected variable has been randomly permutated (Thuiller et al. 2024). Thus, a variable is considered less important for the model if the correlation between both values is higher. Variable importance ranges from 0 to 1, with higher values indicating greater relevance of the predictor and *vice versa* (Cano-Barbacil et al. 2022).

Finally, we applied the same SDM procedure to model the distribution of *M. fossilis*, but restricting the model projections of environmentally suitable areas to its current native range as defined by the IUCN (IUCN 2024). We then converted the probability maps from ensemble models of the three species into binary maps, distinguishing suitable from unsuitable areas. For this purpose, we used the threshold that maximises the True Skill Statistic (TSS), as recommended by Allouche et al. (2006). We assessed the current overlap between the two Asian loach species and *M. fossilis* by calculating the proportion of sites where non-native loaches are currently found within the potential native range of *M. fossilis*. To estimate the potential overlap between the Asian loaches' potential distribution and the current range of *M. fossilis* in Europe, we calculated the proportion of sites where non-native loaches can be found according to our models within the potential native range of *M. fossilis*. All statistical analyses, maps and figures were performed and produced with the software R version 4.2.2 (R Core Team 2023).

3 | Results

3.1 | Distribution Patterns of Asian Loaches

Average cross-validated AUC scores of ensemble models ($AUC_{Pd}=0.957$; $AUC_{Ma}=0.982$) and TSS values ($TSS_{Pd}=0.813$; $TSS_{Ma}=0.909$) were high for both species, reflecting good performance of the two models. High specificity ($specificity_{Pd}=99.3$; $specificity_{Ma}=98.5$) and sensitivity ($sensitivity_{Pd}=94.7$; $sensitivity_{Ma}=96.6$) indicated a great proportion of correctly predicted background points and presences, respectively. Our results also indicated that both loaches have similar distribution patterns (Figures 2 and 3). Annual mean temperature was among the two most important predictors in both cases (Figure 2). *Paramisgurnus dabryanus* and *M. anguillicaudatus* mainly occur in temperate regions with annual mean temperatures ranging from 7°C to 20°C, although *P. dabryanus* appears to inhabit slightly warmer environments (Figure 3). Human footprint was the second most relevant variable for *P. dabryanus* and the fourth most relevant for *M. anguillicaudatus*. Both species were found to be more prevalent in areas with a certain degree of human impact. Aridity was also a highly influential predictor and was negatively related to species occurrence probability. The occurrence of both species was also much influenced by precipitation regimes. More specifically, the distributions of *P. dabryanus* were strongly influenced by seasonal variations in precipitation, while the distribution of *M. anguillicaudatus* was affected by the precipitation of the wettest quarter. In contrast, the number of dams was less relevant in explaining the current distribution of both loach species, although they appeared to be more prevalent in areas not heavily impacted by dams.

3.2 | Range Expansion Potential of Asian Loaches

Both *P. dabryanus* and *M. anguillicaudatus* have the potential to expand their distributions across temperate regions in Europe, North America, South America, Africa, the East coast of Australia and other areas in Asia (Figure 4a). In Europe, *P. dabryanus* could notably spread along the Atlantic coast of the Iberian Peninsula, as well as through Central and Eastern Europe. In North America, *P. dabryanus* may establish populations along the entire West Coast, in Florida, and throughout the Midwest. Similarly, *M. anguillicaudatus* could also expand its range, potentially even more extensively than *P. dabryanus*,

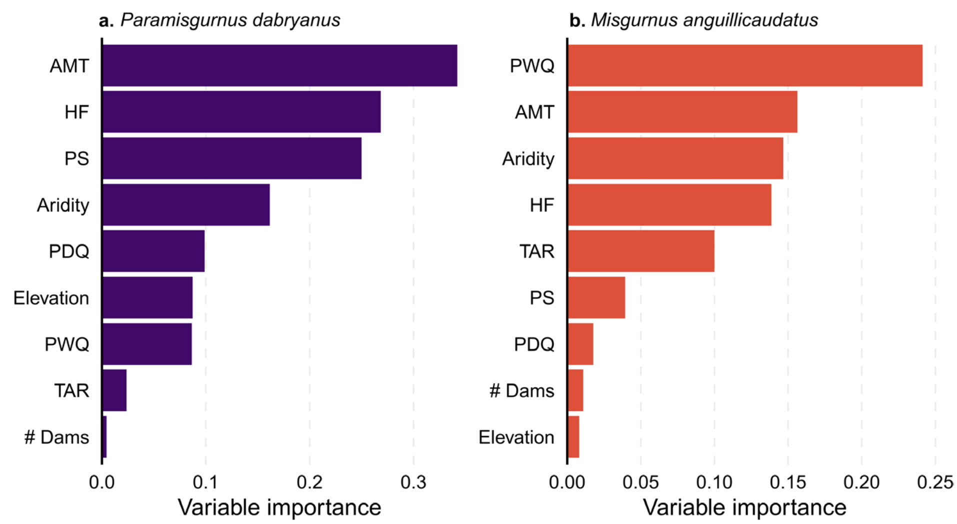

FIGURE 2 | Importance of predictor variables used in the species distribution models for (a) *Paramisgurnus dabryanus* and (b) *Misgurnus anguillicaudatus*. Variable importance ranges from 0 to 1, with higher values indicating greater relevance of the predictor and *vice versa*. AMT = annual mean temperature; TAR = temperature annual range; PS = precipitation seasonality; PWQ = precipitation of wettest quarter; PDQ = precipitation of driest quarter; HF = human footprint.

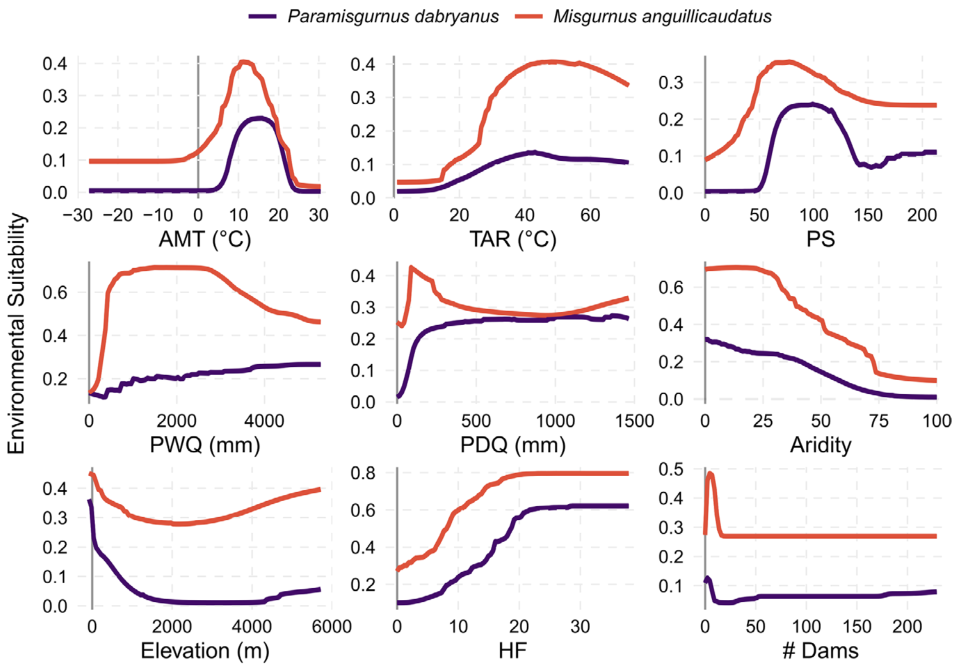

FIGURE 3 | Response curves for *Paramisgurnus dabryanus* and *Misgurnus anguillicaudatus*. The y-axis represents the predicted, marginal environmental suitability, ranging from 0 to 1. Higher values indicate a greater likelihood of the species' occurrence in relation to the environmental variable shown on the *x*-axis. AMT = annual mean temperature; TAR = temperature annual range; PS = precipitation seasonality; PWQ = precipitation of wettest quarter; PDQ = precipitation of driest quarter; HF = human footprint.

across Europe and North America, as well as its current distribution along the eastern and southern coasts of Australia (Figure 4b). In the United States, *M. anguillicaudatus* was predicted to have the potential to spread widely, except in certain regions of the western states like the Rocky Mountains, the Great Basin and the Sierra Nevada. In addition, our results suggest that suitable habitats for both species could exist in South America (e.g., Brazil and Argentina), South Africa and Madagascar.

3.3 | Potential Impact of Asian Loaches on the European Weatherfish *Misgurnus fossilis*

The observed range expansion in both *P. dabryanus* and *M. anguillicaudatus* could lead to increased overlap with *M. fossilis* in Europe. This potential overlap is projected to rise markedly, with *P. dabryanus*'s overlap increasing from the current 0.1% to 4.1%, and *M. anguillicaudatus*'s from 0.2% to 32.8%. More specifically, *P. dabryanus* could impact native populations of *M. fossilis* in Belgium, the Netherlands, Germany, and Austria, as well as some eastern populations in Serbia, Ukraine, and Russia (Figure 5a). *Misgurnus anguillicaudatus* could potentially overlap with nearly all populations of *M. fossilis* in central Europe, except for the northernmost populations and those located east of the Ural Mountains in the far eastern regions of Russia, where its expected impact is lower (Figure 5b).

4 | Discussion

Invasive non-native fish species pose serious ecological threats by disrupting local ecosystems, outcompeting native species, and altering habitat dynamics, often leading to irreversible environmental damage. *Paramisgurnus dabryanus* and *M. anguillicaudatus* are two highly invasive and resilient fish species, recognised for their ability to thrive in diverse environments that pose a notable threat to ecosystems worldwide (Kanou et al. 2007; Keller and Lake 2007; MITECO 2013; Pou-Rovira 2020). By relying on SDMs, our findings suggest that *P. dabryanus* and *M. anguillicaudatus* have the potential to expand their ranges globally. Areas most vulnerable to their respective expansion include temperate zones in Europe, North and South America, the south-eastern coast of Australia, and Asia. Our results also show that both species have a high tolerance to a wide range of temperatures and climatic conditions, being capable of inhabiting areas with diverse climates and environments with high seasonality.

4.1 | Factors Driving Their Range Expansion Success

Although both species share similar distribution patterns, model projections showed that *M. anguillicaudatus* has a greater potential for future range expansion than *P. dabryanus*. Based on our results, both species exhibit a high tolerance to a wide range of temperatures and climatic conditions. Previous studies revealed that *P. dabryanus* can tolerate water temperatures within the range of 10°C–30°C, burrowing into the mud if temperatures exceed this range (Cuinet et al. 2024). Similarly, *M. anguillicaudatus* also demonstrates the ability to tolerate water temperatures ranging from 2°C to 38°C (Strecker et al. 2011; Urquhart and Koetsier 2013), exhibiting high resistance to freezing and enduring direct contact with ice (Urquhart and Koetsier 2013).

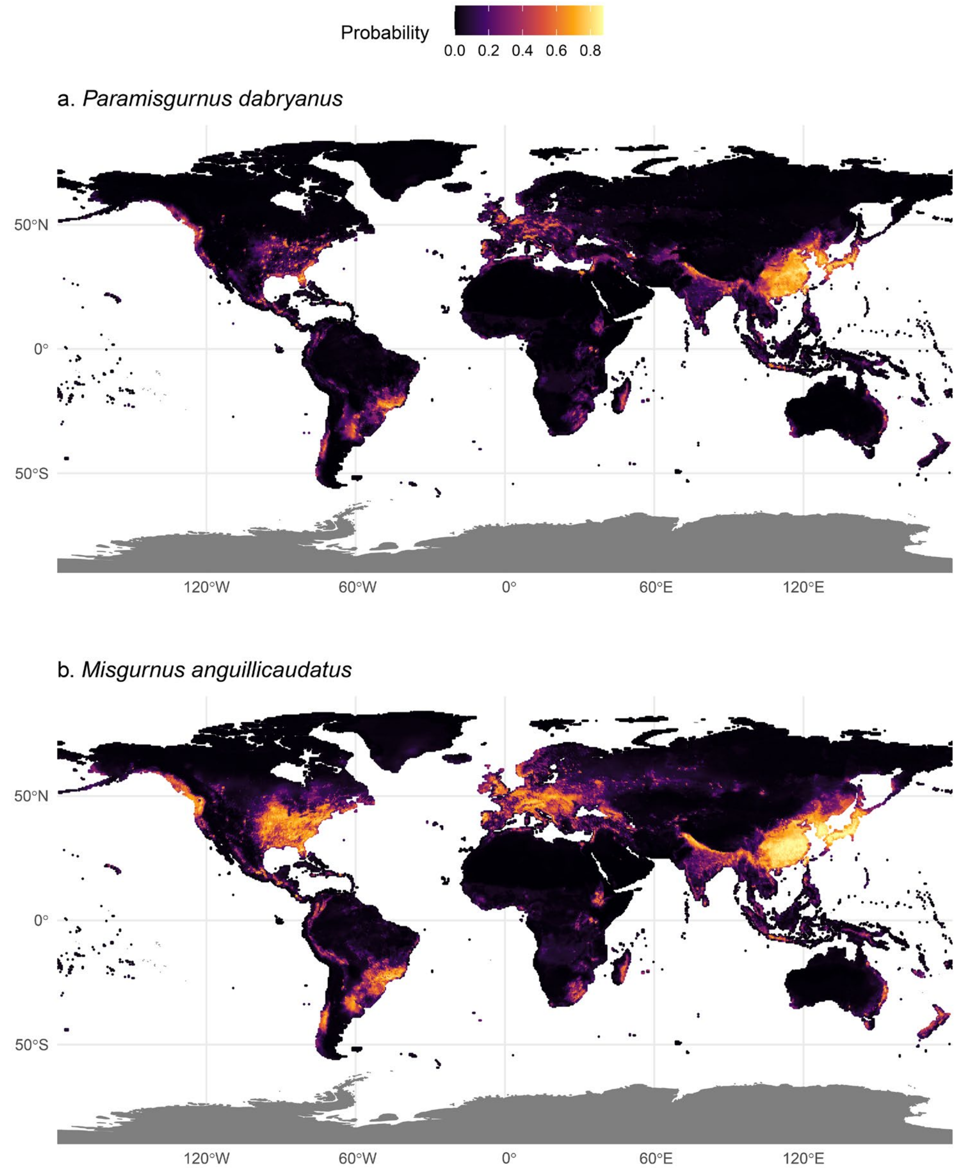

FIGURE 4 | Ensemble forecast of the probability of presence for (a) *Paramisgurnus dabryanus* and (b) *Misgurnus anguillicaudatus*. Brighter colours indicate a higher probability of occurrence.

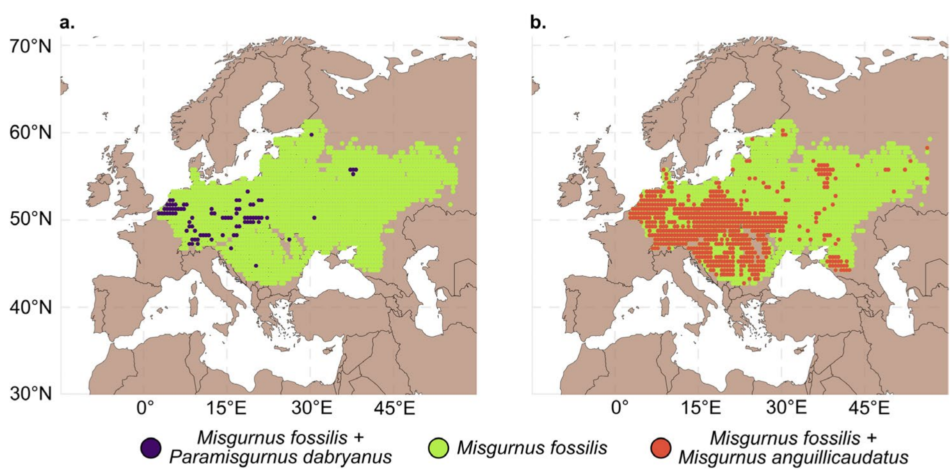

FIGURE 5 | Maps illustrating the potential distribution overlap of (a) *Misgurnus fossilis* and *Paramisgurnus dabryanus*, and (b) *M. fossilis* and *M. anguillicaudatus*.

In addition to broad temperature preferences, both species also demonstrated a broad physiological tolerance to various environmental pressures, including fluctuations in turbidity, dissolved oxygen levels, and the presence of certain pollutants (Tsui et al. 2004; Mcneil and Closs 2007). Their ability to thrive under these conditions suggests that they can persist in modified or altered habitats affected by urbanisation, agriculture or industrial activities. As such, *P. dabryanus* and *M. anguillicaudatus* were more prevalent in areas experiencing a certain degree of human impact. *Paramisgurnus dabryanus* and *M. anguillicaudatus* can inhabit both lotic and lentic environments (Cuinet et al. 2024), as supported by our results, which indicate that the number of dams does not have a relevant effect on their distribution. In fact, in their respective non-native areas, both species have been observed in reservoirs as well as in free-flowing river stretches (Pou-Rovira 2020; Clavero et al. 2023; Cuinet et al. 2024). However, these results should be interpreted with caution, as the native ranges of both modelled Asian loaches are located in heavily human-dominated areas, which may bias the model outcomes and the interpretation of their ecological preferences.

In addition to their broad tolerances, *P. dabryanus* and *M. anguillicaudatus* exhibit several traits that enhance their success as invasive species (Cano-Barbacil et al. 2023b; Clavero et al. 2023). These include a wide range of potential diets (from algae to macroinvertebrates; Kanou et al. 2007), their ability to survive prolonged periods of desiccation by burrowing into the sediment (Pou-Rovira 2020), as well as rapid growth and a high reproductive potential (Froese and Pauly 2023). In fact, they are even able to reproduce by asexual gynogenesis, which accentuates their capacity to establish and rapidly spread in non-native areas (Morishima et al. 2002; You et al. 2008; Fuad et al. 2021). These combined traits not only enhance their resilience in diverse environments but also make them exceptionally difficult to manage, highlighting the urgent need for effective control strategies in regions at risk of invasion.

4.2 | Ecological Impacts of Non-native Asian Loaches

Future introductions and spread leading to growing distributions of *P. dabryanus* and *M. anguillicaudatus* could result in substantial environmental impacts as demonstrated by previous studies (Lintermans et al. 2008; Pou-Rovira 2020). The observed potential overlap between both non-native fish species and European weatherfish *M. fossilis* is particularly concerning for the conservation of this endangered native species. According to our projections, *P. dabryanus* and especially *M. anguillicaudatus* could establish in regions where populations of *M. fossilis* are considered threatened and protected. The main impact mechanisms might be hybridisation and competition as recent studies have demonstrated that despite the considerable genetic distance between *M. anguillicaudatus* and *M. fossilis*, there are no postzygotic barriers for hybridisation (Wanzenböck et al. 2021). However, other benthic organisms can also be at risk from the introduction of non-native Asian loaches. For instance, in Spain, *M. anguillicaudatus* is affecting and competing with other benthic native and endangered fishes such as *Cobitis* spp., *Barbatula* spp. or *Salaria fluviatilis* (MITECO 2013). Similarly, in Australia, significant reductions in aquatic macroinvertebrate diversity and biomass, as well as elevated ammonia, nitrogen and turbidity levels after the introduction of *M. anguillicaudatus* were observed (Lintermans et al. 2008). In addition to the potential risks of hybridisation and competition with native fishes, Asian loaches may pose a sanitary threat by transmitting parasites, such as the nematodes *Contracaecum* spp. or the Asian fish tapeworm *Bothriocephalus acheilognathi*, as well as viral pathogens (e.g., LV-1 Birnavirus) (Lintermans et al. 2008; Cuinet et al. 2024). These parasites can infect other fish species as well as piscivorous birds and mammals (Zhang et al. 2021).

4.3 | Management Implications

Given the broad ecological disruptions posed by *P. dabryanus* and *M. anguillicaudatus*, along with their broad potentially invaded range, their continued spread presents a serious challenge for conservation efforts and ecosystem management on a global scale. Management efforts should therefore prioritise the prevention of new introduction events, as these species exhibit a high invasive capacity, broad ecological tolerance, and are difficult to control (Pou-Rovira 2020; Pyšek et al. 2020). For instance, several unsuccessful attempts to remove *P. dabryanus* from the Vallvidrera Reservoir (Spain) through different control operations between 2015 and 2020 demonstrated the difficulty of managing this species once it is established (Pou-Rovira 2020). Despite the reservoir being drought affected and non-native species being removed, *P. dabryanus* survived buried in the mud. This feature complicates the management of non-native loaches, as effective eradication requires thorough removal and treatment of reservoir sediments. Thus, regular monitoring campaigns are crucial for the early detection of non-native individuals and for implementing management measures before they become established.

Despite the growing concern over the spread of non-native loaches (Clavero et al. 2023), regulatory measures to control their trade remain limited. For example, the large-scale loach *P. dabryanus* has not yet been included in the European Commission's list of "Invasive Alien Species of Union Concern" a designation that would impose restrictions on the import, sale, and distribution of the species throughout the European Union (Jung et al. 2021). This omission allows the continued trade of *P. dabryanus* across EU member states, contributing to its potential spread and establishment in ecosystems outside their native range. Thus, it is essential to include *P. dabryanus* and *M. anguillicaudatus* in national and regional legislations in order to regulate their trade and introduction effectively. This recommendation could potentially be expanded to other non-native species within the *Misgurnus* genus, as some have already been detected in Europe (e.g., *Misgurnus bipartitus*) and may share similar invasive features (Clavero et al. 2023). Finally, more detailed horizon scanning and risk analysis studies could be helpful for identifying particularly sensitive regions (Fredberg et al. 2014; Cano-Barbacil et al. 2023a). Taking proactive steps to address these gaps will be crucial not only for curbing future spread of *P. dabryanus* and *M. anguillicaudatus* but also for safeguarding ecosystems from similar threats posed by other invasive species. By enhancing prevention, monitoring, and regulatory frameworks, we can reduce the risk of long-term ecological disruption and economic losses, as seen with other invasive fish species around the world (Haubrock et al. 2022; Leroy et al. 2023).

4.4 | Research Gaps and Future Directions

While SDMs have proven valuable for predicting habitats at risks of being invaded, our results may be influenced by limitations in observational data and methodological challenges. First, grid-based data, which typically perform well in SDMs, may not fully account for the dendritic nature of river networks, casting doubt on its accuracy for modelling inland fish distributions (but see, Cano-Barbacil et al. 2022). In the case of *P. dabryanus* and *M. anguillicaudatus*, available occurrence data is sparse, especially within their native ranges, where information is scattered and biased toward well-studied, accessible regions. Secondly, the difficulty of accurately identifying these species can lead to errors in presence records. Misidentifications can result in incorrect data being incorporated into models, which in turn may produce misleading predictions about species distributions (Cuinet et al. 2024). Finally, our modelling approach did not consider ecological processes such as competition and biotic interactions with other species, which can affect species' ability to establish in new suitable areas (see e.g., Neves et al. 2021). Without accounting for these biotic interactions, SDMs may wrongly estimate species' potential distribution in some regions. These limitations contribute to an incomplete understanding of the environmental preferences of these species and ecological impacts. Indeed, we believe the range of *P. dabryanus* has been underestimated and that it may extend far beyond our current model projections, both in Europe and the United States. Recent reports, such as its presence in the Rhône catchment in France and its establishment in Catalonia – neither of which were flagged as highly suitable regions by our models – support this view (Clavero et al. 2023; Cuinet et al. 2024).

Furthermore, data on other Asian loaches like *M. bipartitus*, have already detected in Europe (Zangl et al. 2020; Clavero et al. 2023), is even scarcer in global biodiversity databases (BioFresh 2023; GBIF.org 2023a), rendering modelling efforts for these species nearly impossible at the moment. This highlights the urgent need for more comprehensive field-based monitoring studies, including specimen and molecular sampling, to refine our understanding of these emergent non-native species. More targeted surveys are also required in non-native regions to confirm population establishment and identify potentially cryptic populations (Cuinet et al. 2024).

5 | Conclusions

Our study showed that Asian loaches *P. dabryanus* and *M. anguillicaudatus* have a high potential for global range expansions and invasion, with *M. anguillicaudatus* showing a particularly strong ability to establish in new regions. Vulnerable areas include broad regions in Europe, North America and the southeastern coast of Australia. Both species are highly adaptable, tolerating a wide range of temperatures and environmental conditions. The presence of these loaches may pose a threat to native *M. fossilis* and other benthic species through competition, hybridisation and the spread of parasites. While our models provide insights into potential distributions, limitations in data availability may underestimate the true extent of their spread. We strongly recommend further research on the distribution patterns and invasive potential of these species, along with other non-native loaches that are increasingly being introduced beyond their native ranges. Understanding these dynamics is crucial for developing effective management and prevention strategies, as well as for protecting vulnerable regions. Additionally, enhanced surveillance and stricter regulation of activities such as pet trade are essential to prevent the introduction of emerging non-native species into new environments.

Author Contributions

Conceptualisation: C.C.B. Developing methods: C.C.B., J.R. Data analysis: C.C.B., J.R. Preparation of figures and tables: C.C.B., P.J.H. Conducting the research, data interpretation, writing: C.C.B., P.J.H., J.R.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

This article does not include original data. The sources of the species and environmental data used are provided in the main text and Supporting Information. Tables containing occurrence data for the studied species, along with a comprehensive table of the collected environmental variables, are available on figshare (DOI: https://doi.org/10.6084/m9.figshare.27094720).

References

Allouche, O., A. Tsoar, and R. Kadmon. 2006. "Assessing the Accuracy of Species Distribution Models: Prevalence, Kappa and the True Skill Statistic (TSS)." *Journal of Applied Ecology* 43: 1223–1232. https://doi.org/10.1111/j.1365-2664.2006.01214.x.

Bazzichetto, M., M. Malavasi, V. Bartak, A. T. R. Acosta, D. Rocchini, and M. L. Carranza. 2018. "Plant Invasion Risk: A Quest for Invasive Species Distribution Modelling in Managing Protected Areas." *Ecological Indicators* 95: 311–319. https://doi.org/10.1016/j.ecolind.2018.07.046.

Bellard, C., W. Thuiller, B. Leroy, P. Genovesi, M. Bakkenes, and F. Courchamp. 2013. "Will Climate Change Promote Future Invasions?" *Global Change Biology* 19: 3740–3748. https://doi.org/10.1111/gcb.12344.

Bernery, C., C. Bellard, F. Courchamp, et al. 2022. "Freshwater Fish Invasions: A Comprehensive Review." *Annual Review of Ecology, Evolution, and Systematics* 53: 427–456. https://doi.org/10.1146/annurev-ecolsys-032522-015551.

BioFresh. 2023. "Freshwater Biodiversity Data Portal." https://data.freshwaterbiodiversity.eu/#.

Bosch, S., and S. Fernandez. 2016. "sdmpredictors: Species Distribution Modelling Predictor Datasets. 0.2.15."

Briski, E., D. A. R. Drake, F. T. Chan, S. A. Bailey, and H. J. MacIsaac. 2014. "Variation in Propagule and Colonization Pressures Following Rapid Human-Mediated Transport: Implications for a Universal Assemblage-Based Management Model." *Limnology and Oceanography* 59: 2068–2076.

Callaway, R. M., and W. M. Ridenour. 2004. "Novel Weapons: Invasive Success and the Evolution of Increased Competitive Ability." *Frontiers in Ecology and the Environment* 2: 436–443. https://doi.org/10.1890/1540-9295(2004)002[0436:NWISAT]2.0.CO;2.

Cano-Barbacil, C., M. Carrete, P. Castro-Díez, et al. 2023a. "Identification of Potential Invasive Alien Species in Spain Through Horizon Scanning." *Journal of Environmental Management* 345: 118696. https://doi.org/10.1016/j.jenvman.2023.118696.

Cano-Barbacil, C., J. Radinger, and E. García-Berthou. 2022. "The Importance of Seawater Tolerance and Native Status in Mediating the Distribution of Inland Fishes." *Journal of Biogeography* 49: 2037–2049. https://doi.org/10.1111/jbi.14493.

Cano-Barbacil, C., J. Radinger, J. D. Olden, and E. García-Berthou. 2023b. "Estimates of Niche Position and Breadth Vary Across Spatial Scales for Native and Alien Inland Fishes." *Global Ecology and Biogeography* 32: 466–477. https://doi.org/10.1111/geb.13630.

Chapman, D., O. L. Pescott, H. E. Roy, and R. Tanner. 2019. "Improving Species Distribution Models for Invasive Non-Native Species With Biologically Informed Pseudo-Absence Selection." *Journal of Biogeography* 46: 1029–1040. https://doi.org/10.1111/jbi.13555.

Chu, Z., G. Lu, T. Hu, H. Wang, L. Dai, and W. Huang. 2012. "Comparative Analysis on Fecundity of *Misgurnus anguillicaudatus* and *Paramisgurnus dabryanus*." *Hubei Agricultural Sciences* 13: 2794–2796.

Clavero, M., J. Suh, N. Franch, et al. 2023. "Invaders They Are A-Changing: A Recent, Unexpected Surge of Invasive Loaches in Catalonia." *Freshwater Biology* 68: 621–631. https://doi.org/10.1111/fwb.14051.

Cuinet, A., G. Denys, S. Besson, Y. Marchiset, and J. Bouchard. 2024. "First Record of the Large-Scale Loach Misgurnus Dabryanus (Guichenot, 1872) (Teleostei, Cobitidae) in France." *BioInvasions Records* 13: 541–550. https://doi.org/10.3391/bir.2024.13.2.18.

Diagne, C., B. Leroy, R. E. Gozlan, et al. 2020. "InvaCost, a Public Database of the Economic Costs of Biological Invasions Worldwide." *Scientific Data* 7: 277. https://doi.org/10.1038/s41597-020-00586-z.

Dimitriadis, C., C. Marampouti, A. Calò, et al. 2024. "Evaluating the Long Term Effectiveness of a Mediterranean Marine Protected Area to Tackle the Effects of Invasive and Range Expanding Herbivorous Fish on Rocky Reefs." *Marine Environmental Research* 193: 106293. https://doi.org/10.1016/j.marenvres.2023.106293.

Doadrio, I., ed. 2001. *Atlas y Libro Rojo de Los Pesces Continentales de España*. Ministerio de Medio Ambiente.

Early, R., B. A. Bradley, J. S. Dukes, et al. 2016. "Global Threats From Invasive Alien Species in the Twenty-First Century and National Response Capacities." *Nature Communications* 7: 12485. https://doi.org/10.1038/ncomms12485.

Fick, S. E., and R. J. Hijmans. 2017. "WorldClim 2: New 1-Km Spatial Resolution Climate Surfaces for Global Land Areas." *International Journal of Climatology* 37: 4302–4315. https://doi.org/10.1002/joc.5086.

Franklin, J. 2013. "Species Distribution Models in Conservation Biogeography: Developments and Challenges." *Diversity and Distributions* 19: 1217–1223. https://doi.org/10.1111/ddi.12125.

Fredberg, J., L. Thwaites, and J. Earl. 2014. Oriental Weatherloach, *Misgurnus anguillicaudatus*, in the River Murray, South Australia: A Risk Assessment.

Freyhof, J. 2013. "*Misgurnus Fossilis*." The IUCN Red List of Threatened Species 2013: e.T40698A10351495.

Froese, R., and D. Pauly. 2023. *FishBase*. World Wide Web electronic publication. https://www.fishbase.org.

Fuad, M. M. H., L. Vetešník, and A. Šimková. 2021. "Is Gynogenetic Reproduction in Gibel Carp (*Carassius gibelio*) a Major Trait Responsible for Invasiveness?" *Journal of Vertebrate Biology* 70: 21049. https://doi.org/10.25225/jvb.21049.

Gallardo, B., D. C. Aldridge, P. González-Moreno, et al. 2017. "Protected Areas Offer Refuge From Invasive Species Spreading Under Climate Change." *Global Change Biology* 23: 5331–5343. https://doi.org/10.1111/gcb.13798.

Gallardo, B., M. Clavero, M. I. Sánchez, and M. Vilà. 2016. "Global Ecological Impacts of Invasive Species in Aquatic Ecosystems." *Global Change Biology* 22: 151–163. https://doi.org/10.1111/gcb.13004.

Gallardo, B., A. Zieritz, and D. C. Aldridge. 2015. "The Importance of the Human Footprint in Shaping the Global Distribution of Terrestrial, Freshwater and Marine Invaders." *PLoS One* 10, no. 5: e0125801. https://doi.org/10.1371/journal.pone.0125801.

GBIF.Org. 2023a. "GBIF Home Page." https://www.gbif.org.

GBIF.Org. 2023b. "GBIF Occurrence Download: *Paramisgurnus dabryanus*." https://doi.org/10.15468/dl.ccb3jj.

GBIF.Org. 2024a. "GBIF Occurrence Download: *Misgurnus anguillicaudatus*." https://doi.org/10.15468/dl.2b9x6y.

GBIF.Org. 2024b. "GBIF Occurrence Download: *Misgurnus fossilis*." https://doi.org/10.15468/dl.zrenzm.

Genovesi, P., C. Carboneras, M. Vilà, and P. Walton. 2015. "EU Adopts Innovative Legislation on Invasive Species: A Step Towards a Global Response to Biological Invasions?" *Biological Invasions* 17: 1307–1311. https://doi.org/10.1007/s10530-014-0817-8.

Gippet, J. M. W., and C. Bertelsmeier. 2021. "Invasiveness Is Linked to Greater Commercial Success in the Global Pet Trade." *Proceedings of the National Academy of Sciences* 118, no. 14: e2016337118. https://doi.org/10.1073/pnas.2016337118.

Guisan, A., R. Tingley, J. B. Baumgartner, et al. 2013. "Predicting Species Distributions for Conservation Decisions." *Ecology Letters* 16: 1424–1435. https://doi.org/10.1111/ele.12189.

Hartvich, P., S. Lusk, and J. Rutkayová. 2010. "Threatened Fishes of the World: *Misgurnus fossilis* (Linnaeus, 1758) (Cobitidae)." *Environmental Biology of Fishes* 87: 39–40. https://doi.org/10.1007/s10641-009-9564-6.

Haubrock, P. J., C. Bernery, R. N. Cuthbert, et al. 2022. "Knowledge Gaps in Economic Costs of Invasive Alien Fish Worldwide." *Science of the Total Environment* 803: 149875. https://doi.org/10.1016/j.scitotenv.2021.149875.

Hazelton, P. D., and G. D. Grossman. 2009. "Turbidity, Velocity and Interspecific Interactions Affect Foraging Behaviour of Rosyside Dace (*Clinostomus funduloides*) and Yellowfin Shiners (Notropis Lutippinis)." *Ecology of Freshwater Fish* 18: 427–436. https://doi.org/10.1111/j.1600-0633.2009.00359.x.

He, K. S., B. A. Bradley, A. F. Cord, et al. 2015. "Will Remote Sensing Shape the Next Generation of Species Distribution Models?" *Remote Sensing in Ecology and Conservation* 1: 4–18. https://doi.org/10.1002/rse2.7.

Hijmans, R. J., M. Barbosa, A. Ghosh, and A. Mandel. 2024. "geodata: Download Geographic Data."

IUCN. 2024. "The IUCN Red List of Threatened Species." Version 2023-1.

Jarvis, A., H. I. Reuter, A. Nelson, and E. Guevara. 2008. "Hole-Filled Seamless SRTM Data V4, International Centre for Tropical Agriculture (CIAT)." https://srtm.csi.cgiar.org.

Jung, M., C. Ratschan, G. Zauner, T. Friedrich, and L. Zangl. 2021. *Erste Nachweise des Nordchinesischen Schlammpeitzgers (Misgurnus bipartitus Sauvage & Dabry de Thiersant, 1874) und Ausbreitung in Österreich*. Zeitschrift des Österreichischen Fischereiverbandes.

Kanou, K., S. Saito, S. Fuchigami, A. Imamura, H. Imai, and Y. Taki. 2007. "Occurrence Patterns and Food Habits of Introduced Alien Loach

Paramisgurnus dabryanus and Native Loach *Misgurnus anguillicaudatus* at Irrigation Drainages Around Rice Fields in the Watarase River System, Central Honshu, Japan." *Aquaculture Science* 55: 109–114.

Keller, R. P., and P. S. Lake. 2007. "Potential Impacts of a Recent and Rapidly Spreading Coloniser of Australian Freshwaters: Oriental Weatherloach (*Misgurnus anguillicaudatus*)." *Ecology of Freshwater Fish* 16: 124–132. https://doi.org/10.1111/j.1600-0633.2006.00204.x.

Kirsch, J. E., R. F. Feeney, A. Goodbla, et al. 2018. "First Record of the Large-Scale Loach *Paramisgurnus dabryanus* (Cobitidae) in the United States." *Journal of Fish and Wildlife Management* 9, no. 1: 246–254. https://doi.org/10.3996/012017-JFWM-008.

Kottelat, M., and J. Freyhof. 2007. *Handbook of European Freshwater Fishes*. Kottelat, Cornol, Switzerland & Freyhof.

Leroy, B., C. Bellard, M. S. Dias, et al. 2023. "Major Shifts in Biogeographic Regions of Freshwater Fishes as Evidence of the Anthropocene Epoch." *Science Advances* 9, no. 46: eadi5502. https://doi.org/10.1126/sciadv.adi5502.

Levine, J. M., and C. M. D'Antonio. 2003. "Forecasting Biological Invasions With Increasing International Trade." *Conservation Biology* 17: 322–326. https://doi.org/10.1046/j.1523-1739.2003.02038.x.

Lintermans, M., T. Raadik, D. Morgan, and P. Jackson. 2008. *Emerging Issues in Alien Fish Management in the Murray-Darling Basin: Statement, Recommendations and Supporting Papers*, 22–32. Murray-Darling Basin Commission.

Marmion, M., M. Parviainen, M. Luoto, R. K. Heikkinen, and W. Thuiller. 2009. "Evaluation of Consensus Methods in Predictive Species Distribution Modelling." *Diversity and Distributions* 15: 59–69. https://doi.org/10.1111/j.1472-4642.2008.00491.x.

Mcneil, D. G., and G. P. Closs. 2007. "Behavioural Responses of a South-East Australian Floodplain Fish Community to Gradual Hypoxia." *Freshwater Biology* 52: 412–420. https://doi.org/10.1111/j.1365-2427.2006.01705.x.

MITECO. 2013. "Catálogo Español de Especies Exóticas Invasoras: *Misgurnus anguillicaudatus*."

Morishima, K., S. Horie, E. Yamaha, and K. Arai. 2002. "A Cryptic Clonal Line of the Loach *Misgurnus anguillicaudatus* (Teleostei: Cobitidae) Evidenced by Induced Gynogenesis, Interspecific Hybridization, Microsatellite Genotyping and Multilocus DNA Fingerprinting." *Zoological Science* 19: 565–575. https://doi.org/10.2108/zsj.19.565.

Murphy, C. A., G. Grenouillet, and E. García-Berthou. 2015. "Natural Abiotic Factors More Than Anthropogenic Perturbation Shape the Invasion of Eastern Mosquitofish (*Gambusia holbrooki*)." *Freshwater Science* 34: 965–974. https://doi.org/10.1086/681948.

Neves, M. P., R. Costa-Pereira, R. L. Delariva, and C. B. Fialho. 2021. "Seasonality and Interspecific Competition Shape Individual Niche Variation in Co-Occurring Tetra Fish in Neotropical Streams." *Biotropica* 53: 329–338. https://doi.org/10.1111/btp.12879.

Pou-Rovira, Q. 2020. "Plan de Erradicación de Paramisgurnus Dabryanus: Actuación de Descaste Intensivo en al Riera de Vallvidrera. Informe Final."

Pyšek, P., P. E. Hulme, D. Simberloff, et al. 2020. "Scientists' Warning on Invasive Alien Species." *Biological Reviews* 95: 1511–1534. https://doi.org/10.1111/brv.12627.

R Core Team. 2023. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.

Radinger, J., J. D. Alcaraz-Hernández, and E. García-Berthou. 2019. "Environmental Filtering Governs the Spatial Distribution of Alien Fishes in a Large, Human-Impacted Mediterranean River." *Diversity and Distributions* 25: 701–714. https://doi.org/10.1111/ddi.12895.

Santis, V. D., S. Brignone, M. Čech, et al. 2024. "LIFE PREDATOR: Prevent, Detect, Combat the Spread of *Silurus glanis* in South European Lakes to Protect Biodiversity." *NeoBiota* 93: 225–244. https://doi.org/10.3897/neobiota.93.105200.

Seebens, H., T. M. Blackburn, E. E. Dyer, et al. 2017. "No Saturation in the Accumulation of Alien Species Worldwide." *Nature Communications* 8: 14435. https://doi.org/10.1038/ncomms14435.

Simberloff, D., J.-L. Martin, P. Genovesi, et al. 2013. "Impacts of Biological Invasions: What's What and the Way Forward." *Trends in Ecology & Evolution* 28: 58–66. https://doi.org/10.1016/j.tree.2012.07.013.

Soto, I., P. Balzani, L. Carneiro, et al. 2024. "Taming the Terminological Tempest in Invasion Science." *Biological Reviews*. https://doi.org/10.32942/X24C79.

Stoeckle, B. 2019. "Molecular Confirmation of the Large-Scale Loach *Paramisgurnus dabryanus* Dabry de Thiersant, 1872 (Cypriniformes, Cobitidae) in Europe." *BioInvasions Records* 8: 419–426. https://doi.org/10.3391/bir.2019.8.2.24.

Strecker, A. L., P. M. Campbell, and J. D. Olden. 2011. "The Aquarium Trade as an Invasion Pathway in the Pacific Northwest." *Fisheries* 36: 74–85. https://doi.org/10.1577/03632415.2011.10389070.

Su, G., M. Logez, J. Xu, S. Tao, S. Villéger, and S. Brosse. 2021. "Human Impacts on Global Freshwater Fish Biodiversity." *Science* 371: 835–838. https://doi.org/10.1126/science.abd3369.

Thuiller, W., D. Georges, M. Gueguen, R. Engler, F. Breiner, and B. Lafourcade. 2024. "biomod2: Ensemble Platform for Species Distribution Modeling." 4.2-5–2.

Thuiller, W., B. Lafourcade, R. Engler, and M. B. Araújo. 2009. "BIOMOD – A Platform for Ensemble Forecasting of Species Distributions." *Ecography* 32: 369–373. https://doi.org/10.1111/j.1600-0587.2008.05742.x.

Tingley, R., P. García-Díaz, C. R. R. Arantes, and P. Cassey. 2018. "Integrating Transport Pressure Data and Species Distribution Models to Estimate Invasion Risk for Alien Stowaways." *Ecography* 41: 635–646. https://doi.org/10.1111/ecog.02841.

Tsui, T. K. N., D. J. Randall, L. Hanson, A. P. Farrell, S. F. Chew, and Y. K. Ip. 2004. "Dogmas and Controversies in the Handling of Nitrogenous Wastes: Ammonia Tolerance in the Oriental Weatherloach *Misgurnus anguillicaudatus*." *Journal of Experimental Biology* 207, no. 12: 1977–1983. https://doi.org/10.1242/jeb.00905.

Tulloch, A. I. T., V. J. D. Tulloch, M. C. Evans, and M. Mills. 2014. "The Value of Using Feasibility Models in Systematic Conservation Planning to Predict Landholder Management Uptake." *Conservation Biology* 28: 1462–1473.

Urquhart, A. N., and P. Koetsier. 2013. "Low-Temperature Tolerance and Critical Thermal Minimum of the Invasive Oriental Weatherfish *Misgurnus anguillicaudatus* in Idaho, USA." *Transactions of the American Fisheries Society* 143, no. 1: 68–76. https://doi.org/10.1080/00028487.2013.829124.

Venter, O., E. W. Sanderson, A. Magrach, et al. 2016. "Sixteen Years of Change in the Global Terrestrial Human Footprint and Implications for Biodiversity Conservation." *Nature Communications* 7: 12558. https://doi.org/10.1038/ncomms12558.

Wanzenböck, J., M. Hopfinger, S. Wanzenböck, L. Fuxjäger, H. Rund, and D. K. Lamatsch. 2021. "First Successful Hybridization Experiment Between Native European Weatherfish (*Misgurnus fossilis*) and Non-Native Oriental Weatherfish (*M. anguillicaudatus*) Reveals no Evidence for Postzygotic Barriers." *NeoBiota* 69: 29–50. https://doi.org/10.3897/neobiota.69.67708.

You, C., X. Yu, D. Tan, and J. Tong. 2008. "Gynogenesis and Sex Determination in Large-Scale Loach *Paramisgurnus dabryanus* (Sauvage)." *Aquaculture International* 16: 203–214. https://doi.org/10.1007/s10499-007-9138-6.

You, C., X. Yu, and J. Tong. 2009. "Detection of Hybridization Between Two Loach Species (Paramisgurnus Dabryanus and *Misgurnus* *anguillicaudatus*) in Wild Populations." *Environmental Biology of Fishes* 86: 65–71. https://doi.org/10.1007/s10641-007-9282-x.

Zangl, L., M. Jung, W. Gessl, S. Koblmüller, and C. Ratschan. 2020. "Oriental or Not: First Record of an Alien Weatherfish (Misgurnus) Species in Austria Verified by Molecular Data." *BioInvasions Records* 9, no. 2: 375–383. https://doi.org/10.3391/bir.2020.9.2.23.

Zhang, A. T., and V. X. Gu. 2023. "Global Dam Tracker: A Database of More Than 35,000 Dams With Location, Catchment, and Attribute Information." *Scientific Data* 10: 111. https://doi.org/10.1038/s41597-023-02008-2.

Zhang, C., Z. Wang, B. Zhang, H. Yang, and Z. Gu. 2021. "An Investigation of Zoonotic Nematodes of Loach *Paramisgurnus dabryanus* Dabry de Thiersant, Under High-Density Pond Farming Pattern in China." *Aquaculture* 540: 736666. https://doi.org/10.1016/j.aquaculture.2021.736666.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.