

Invasive Freshwater Fishes and the Decline of Native Biodiversity: A Review of Tilapia and Pangasius Impacts on Pakistan's Indus River System

Rabia Fatima*

Department of Zoology, University of Agriculture Faisalabad, Constituent College Toba Tek Singh, Pakistan Email: rabiafatimabusri2002@gmail.com

Maliha Sarfraz*

Department of Zoology, University of Agriculture Faisalabad, Constituent College Toba Tek Singh, Pakistan Email: maliha.sarfraz@uaf.edu.pk

Ayesha Akram

Department of Zoology, University of Agriculture Faisalabad, Constituent College Toba Tek Singh, Pakistan

Noor-ul-Huda

Department of Zoology, University of Agriculture Faisalabad, Constituent College Toba Tek Singh, Pakistan

Hayat Ullah

Department of Chemistry, University of Okara, Okara-56130, Pakistan

ABSTRACT

Few examples could be more dramatic than the global invasion of tilapia (*Oreochromis* spp.) and pangasius (*Pangasianodon hypophthalmus*) to illustrate the leading cause of biodiversity loss: invasive freshwater fishes. Both species were intentionally introduced to enhance aquaculture and food security, and have become feral populations that are competing with, displacing and otherwise interfering with native fish populations. This review aims to highlight the pathways, biological attributes and ecological processes involved in the success of these two invasive species and in particular in South Asia, including the Indus River system in Pakistan. Across studies, there are converging patterns: tilapia and pangasius grow rapidly, have broad environmental tolerances, are highly fecund, and are generalist feeders, meaning they outcompete native fish for food and spawning space, destroy habitat structure, affect food-web dynamics, and in some cases spread disease. The native species richness of the rivers examined at the habitat level has declined from approximately 72% of the individuals in low-disturbance upstream rivers to approximately 22% in heavily modified downstream reaches, reflecting an increase in invasive dominance in the latter. The species richness, Shannon diversity and

evenness are significantly lower at sites invaded than at similar non-invaded sites. Such pressures reduce the complexity of fish communities and encourage biotic homogenization and have the potential to drive freshwater systems into alternative stable states that are less favourable but more difficult to recover. Meanwhile, the characteristics that make these species a nuisance to native biodiversity also make them beneficial to aquaculture-based livelihoods, and thus there are continuing conflicts between aquaculture and conservation of native biodiversity. Weak biosecurity governance, poor long-term monitoring, and inadequate public awareness are the key factors that cause invasions to be unknown until they are firmly established, and it suggests that better regulation, restoration of habitats, and long-term ecological monitoring are priorities to manage this trade-off.

Keywords: invasive species; *Oreochromis*; *Pangasianodon hypophthalmus*; freshwater biodiversity; Indus River; biotic homogenization; aquaculture

1. Introduction

Freshwater ecosystems (rivers, lakes, wetlands and reservoirs) account for less than one per cent of the earth's surface but provide water for drinking, irrigation, nutrient cycling and flood control that support human welfare and also host a disproportionately large share of biodiversity (Reid et al., 2019). Pollution, agricultural runoff, habitat fragmentation and temperature and hydrology changes due to climate change are all increasingly affecting these systems and are some of the most rapidly degraded ecological systems in the world.

Biological invasion is one of the most important factors affecting biodiversity loss globally (Blackburn et al., 2019), and is a pressure to freshwater systems. Introduced species are those that have become invasive when they have established a reproducing population outside of their native range and are causing measurable ecological, economic or social damage (Gallardo et al., 2016). Although not all introduced fishes are invasive, those that are often have a set of similar traits that allow them to outcompete native species, such as fast growth rate, high fecundity, broad environmental tolerance, and generalist feeding (Kolar & Lodge, 2016). Freshwater systems are particularly susceptible to these invasions since they are connected and heavily used by human activities.

The dominant species of this literature are Nile tilapia (*Oreochromis niloticus* and related *Oreochromis* spp.) and striped catfish or pangasius (*Pangasianodon hypophthalmus*). Both are important aquaculture commodities for their ability to grow quickly, withstand low water quality and have high market demand (El-Sayed, 2019; Bush & Belton, 2018) and both have been released (either accidentally or intentionally) in natural waters throughout Africa, Asia and Latin America. In Pakistan, their introduction has been closely associated with expansion of aquaculture in the Indus River system where they have been introduced alongside very high biodiversity of indigenous fish species, such as carps and catfishes that are of economic importance, as well as many small indigenous species (Khan et al., 2016;

Bibi et al., 2018).

The main objectives of this review are to map the pathways and drivers that led to the introduction of tilapia and pangasius, understand the biological characteristics that have contributed to their success of invasion, identify how they are impacting native fish diversity, and summarize the reported patterns of invasion in the Indus basin, and assess the subsequent impacts at the ecosystem level and socio-economic consequences.

2. Methodology

This review is based on the systematic screening of peer-reviewed and grey literature on freshwater fish community assessment, invasion ecology and aquaculture, focusing on specific studies on tilapia and pangasius. Sources were considered relevant, of good scientific methodology and applicable to their respective regions; preference was given to research on South Asian and Indus basin systems where applicable. The review provides a synthesis of the findings of the various primary studies rather than new primary data, because different approaches were used for different studies, including stratified sampling, random sampling, systematic sampling, fish identification by morphological, morphometric and taxonomic methods, water quality analysis, and analysis of biodiversity indexes (Shannon index, Simpson index, ANOVA, correlation, regression, multivariate methods, etc.) across various river, canal, reservoir and wetland sections. All figures and tables presented here are summarising trends found in the literature examined and in particular the comparative habitat and biodiversity data presented by Xenopoulos et al. (2017) and Gallardo et al. (2019).

3. Introduction Pathways and Drivers

Aquaculture is always identified as the biggest source of fish invasions worldwide, mainly as a result of escapes from poorly stocked ponds or cages during flood conditions or during infrastructure failure (Azzurro et al., 2019). This risk is increased if the regulatory regime is lax and farmed stock can access nearby rivers and canals without adequate controls. Ricciardi (2017) views invasion as a result of many interacting human activities, rather than a single pathway, such as through the ornamental trade, recreational stocking, ballast-water discharge, and accidental co-transport during shipping, and predicts that climate change will place more habitats within the reach of these species as temperatures and hydrological regimes change.

In Pakistan, exotic fish have been introduced closely associated with the expansion of aquaculture. Common carp and Chinese carp species were introduced first followed by tilapia and pangasius as they are suitable species for intensive farming (FAO, 2020). Since then, deliberate stocking, accidental escapes and the ornamental fish trade have spread these species through the interconnected reservoirs, dams and irrigation canals of the Indus system, their spread largely unrecorded because of poor monitoring. (Naeem et al., 2021)

4. Biological basis of invasion success

4.1 Tilapia

Tilapia species are of African origin and are considered to have evolved throughout

the Rift Valley lakes and the Nile and Congo river system (FAO, 2017). They are widely distributed throughout the world, and have an especially unusual suite of reproductive and physiological characteristics: high fecundity, rapid maturation of juveniles, and high survival rates in early life stages due to maternal mouth-brooding (Fitzsimmons, 2016). Tilapia are also relatively tolerant of low levels of dissolved oxygen, temperature, salinity and pH, and switch feeding habits when the preferred food source is absent, which can lead to high densities in impaired habitats not used by native fish (de Silva et al., 2017). Tilapia are not only tolerant, but they also actively modify the habitats they occupy, by feeding and nesting that lead to disturbance of sediments and displacement of aquatic plants, which increases turbidity and decreases primary production (Yongo et al., 2018). Hybridization with highly related native cichlids can lead to genetic introgression that may destroy locally adapted gene pools permanently (Shechonge et al., 2019).

4.2 Pangasius

Pangasiopsis hypophthalmus is an indigenous species of Mekong basin which has been cultivated as one of the most economically important species in the world because of its very good growth performance (1–2 kg in 8–12 months), the good feed conversion ratio and the high demand for exports in which Vietnam alone has produced hundreds of thousands of metric tons per year (Bush & Belton, 2018). It can withstand the level of dissolved oxygen as low as 0.5–1.0 mg/L and the stocking density is high, up to more than 100 kg/m³, which is advantageous in the pond with low oxygen content; however, it will also survive and settle in natural waters with low nutrient contents or environmental degradation (Anh et al., 2016). Intensive rearing of pangasius also produces significant nutrient loading (nitrogen, phosphates, feed wastes, metabolic wastes) which contributes to eutrophication and low levels of dissolved oxygen in water bodies, and during flooding or pond failures, large size, bottom dwelling fish species enter into fish communities as a competitor with pangasius (Dinh et al., 2020; Naeem et al., 2021).

4.3 Comparative Traits

The comparative biological characteristics of tilapia, pangasius and native fish are summarized in Table 1 on average. In almost all traits (growth rate, temperature tolerance, feeding breadth, reproductive rate, habitat tolerance, and competitive ability) the two invasive species are more successful than the average of the native species, which are the traits most commonly cited as being responsible for their invasive success (Gallardo et al., 2019).

Table 1. Comparative biological traits of tilapia, pangasius, and native species (adapted from Gallardo et al., 2019).

Trait	Tilapia	Pangasius	Native species (avg.)
Growth rate	Very fast	Fast	Moderate
Temperature tolerance	Wide (15–40 °C)	Wide (18–38 °C)	Narrow (18–28 °C)

Feeding habit	Omnivorous (broad)	Omnivorous (deep)	Specialized
Reproductive rate	Very high	High	Moderate–low
Habitat tolerance	High (disturbed)	High (deep/turbid)	Low (specific)
Competitive ability	Dominant	Moderate–dominant	Variable

5. How it affects native fish

5.1. Resource Competition and Behavioral Dominance

Most often mentioned reasons for decline are direct competition for food and space, especially in nutrient poor systems where the native populations are already stressed for resources (Havel et al., 2015; Tran et al., 2018, Taha et al, 2017). In addition to their superior access to shared resources, invasive generalists gain an even greater competitive edge from their behavioral dominance: many of the invasive fish are highly territorial, and they can monopolize good habitat even if resources are not really limiting (Banha et al., 2016). Feeding overlap is significant: tilapia's omnivorous grazing behavior puts it in direct competition with native planktivores and benthivores, while pangasius additionally puts pressure on other trophic levels by its deep-water foraging (Liu et al., 2017). Such exclusion can stress native fish over time, reduce their growth and reproductive capacity, and lead to slow population declines or extirpation (Cucherousset & Olden, 2016).

5.2 Reproductive Interference

Invasive species also directly limit the reproduction of native species. Tilapia aggressively compete for breeding territories in shallow, vegetated spawning habitat that native fish use; tilapia is either physically capable of excluding native fish or raising stress hormones that inhibit reproduction of native fish (Roe et al., 2017; Duncan et al., 2019). Pangasius do not possess the territoriality trait, but it can disrupt the sediment and vegetation that native eggs depend on for attachment and protection and therefore can indirectly affect hatching success (Luong et al., 2020). Some invasive species also prey on eggs and larvae (Copp et al., 2016), which further decreases recruitment, and can cause a sharp drop in the number of individuals of species with narrow reproductive requirements (Courtenay & Wainwright, 2018).

5.3 Habitat Degradation

When invasive fish feed and nest, they create disturbance of bottom sediments, turbidity and light penetration, leading to the loss of aquatic vegetation and habitat for aquatic life (Kopf et al., 2017). This is further exacerbated by benthic invertebrate degradation, which is causing an additional competitive challenge, for native bottom-feeding fish already facing a competitive challenge (Cuthbert et al., 2021).

The transmission of disease and parasites to plants.

Invasive fish may also carry new pathogens and parasites that native species are not immune to, and can also have high population densities which can lead to greater

contact rates and disease transmission. In some cases, invasive species serve as a reservoir host and are able to support the transmission of a pathogen without the presence of the native host if the native host has become too scarce to sustain pathogen transmission alone (Lymbery et al., 2016).

Table 2. Summary of invasive-species impact mechanisms and reported outcomes for native fish (adapted from Jackson & Britton, 2018).

Impact category	Mechanism	Affected species	Reported outcome
Resource competition	Food & habitat overlap	Most native cyprinids	Population decline (30–55%)
Reproductive interference	Spawning-site exclusion	Shallow-water spawners	Reduced recruitment
Habitat degradation	Turbidity, vegetation loss	Vegetation-dependent spp.	Breeding habitat loss
Trophic disruption	Food-web restructuring	Multiple trophic levels	Reduced prey availability
Behavioral displacement	Aggression & territoriality	Small-bodied natives	Spatial displacement
Biotic homogenization	Invasive dominance across sites	Community-level	Loss of local uniqueness

6. Patterns of Invasion reported in the Indus Basin

South Asia is a global hotspot of freshwater fish diversity and has high endemism rate for many river basins (Reid et al., 2019). The Indus system in Pakistan is a large watercourse (about 3,000 km long) supporting commercially important carps and catfishes and many small endemic fishes of high conservation value that provide livelihoods for large fishing populations (Bibi et al., 2018; Ali et al., 2020). All of these systems are subjected to industrial effluents, agricultural runoff, untreated sewage and disruptions to natural flow patterns from dams, barrages and irrigation infrastructure, which affects water quality and impacts the natural flow pattern upon which native fish depend for reproduction (Shah et al., 2019; Tickner et al., 2020).

6.1 Habitat-Level Species Composition

Research that has compared the composition of species from various habitat types consistently shows that native fish are more common in low-disturbance reaches upstream, while invasive species (mostly tilapia and pangasius) are more common in highly agricultural and urbanised reaches downstream (Xenopoulos et al., 2017; Olden et al., 2018).

Table 3. Species composition summary by habitat type (adapted from Xenopoulos et al., 2017).

Habitat type	Native spp. (%)	Invasive spp. (%)	Dominant family	Disturbance level
Upstream rivers	72%	12%	Cyprinidae / Siluridae	Low
Wetlands	65%	20%	Cyprinidae	Low–moderate
Reservoirs	48%	38%	Mixed	Moderate
Canals	35%	55%	Cichlidae (Tilapia)	High
Downstream rivers	22%	70%	Cichlidae / Pangasiidae	High

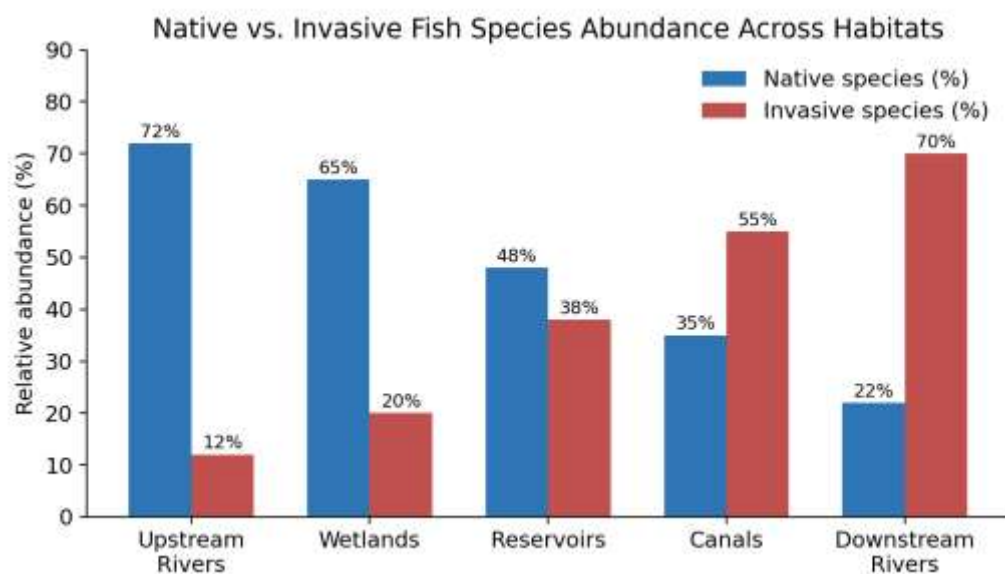


Figure 1. Relative abundance of native vs. invasive fish species across surveyed habitats (adapted from Xenopoulos et al., 2017).

With elevated water temperature, invasive species are expected to be more abundant in the warmer months due to increased reproduction and juvenile growth, while native species are less abundant in the warmer months indicating a seasonal competitive advantage of the invasive taxa under warming conditions (Britton et al., 2018; Jackson et al., 2020). Trophic overlap studies also reveal that shared resources are often being competed for by invasive and native fish species in the same zone, with the shared niche more often occupied by the invasive species, leaving less resources

for the native fish species (Kumschick et al, 2018).

6.3 Abundance Trends and Aquaculture Linkages

The abundance of tilapia and pangasius has increased steadily in most of the sampled locations, which are in high-density water bodies with high nutrient and ecological disturbance concentration, i.e. the conditions that are least favorable for the native species (Cucherousset & Olden, 2016). The regional pattern is similar to the international growth of pangasius and tilapia aquaculture production; the amount of frozen tilapia and pangasius fillet imports/production is shown in Figure 2, and represents an indicator of the scale of aquaculture activity that underlies the feral establishment risk in receiving waters.

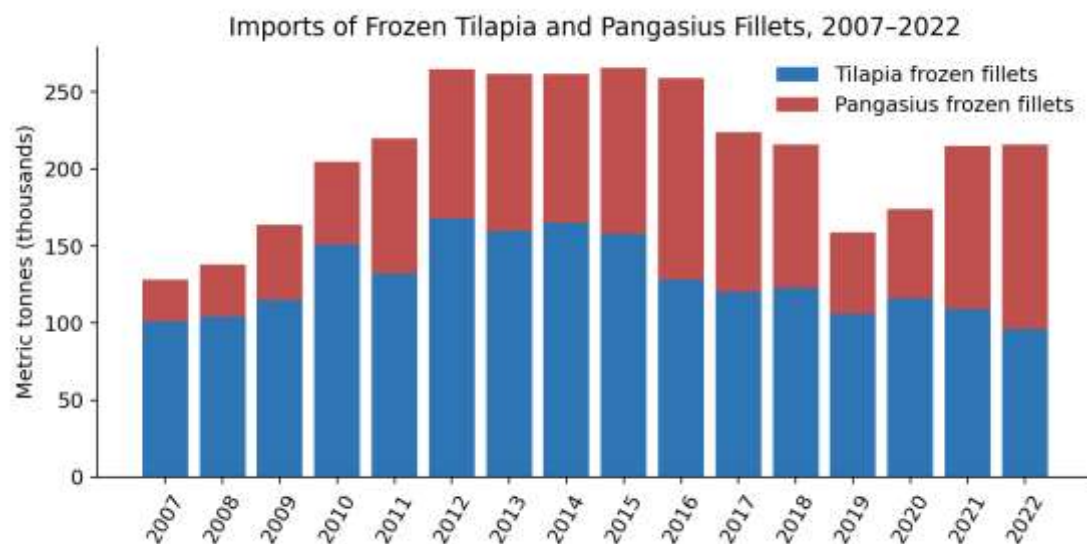


Figure 2. Reported imports of frozen tilapia and pangasius fillets, 2007–2022, illustrating the scale of global aquaculture supply underlying feral establishment risk (adapted from Cucherousset & Olden, 2016).

6.4 Biodiversity Outcomes

Invaded sites vs. non-invaded sites compare well with the resource-competition and habitat-degradation mechanisms described in Section 5, with substantially lower species richness, Shannon diversity, Simpson diversity and evenness reported at invaded sites. (Gallardo et al., 2019) These differences are summarized in Figure 3 for the four indices that are most frequently reported.

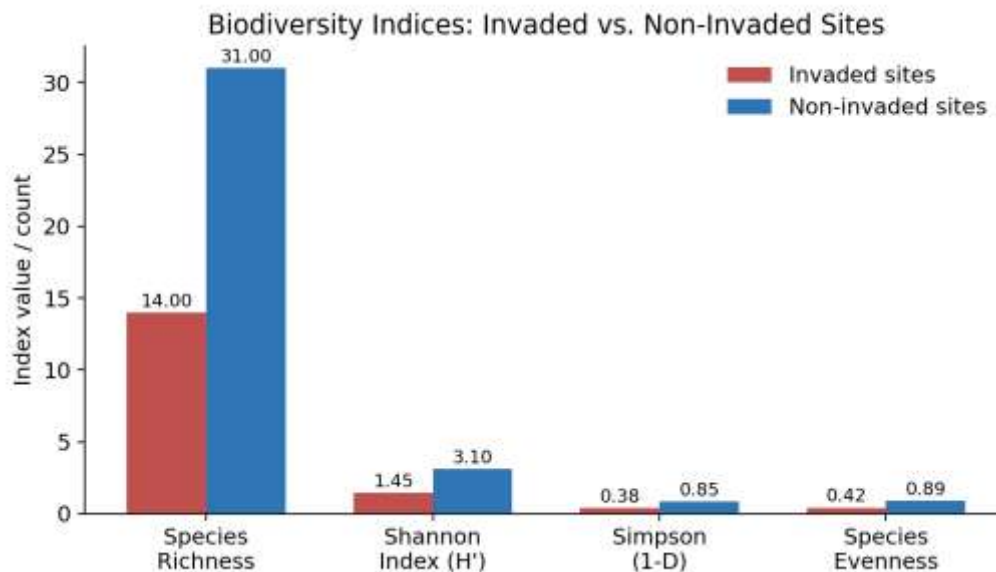


Figure 3. Biodiversity indices compared between invaded and non-invaded sites (adapted from Gallardo et al., 2019).

7. Ecosystem-Level Consequences

All of these together drive a re-structuring of freshwater food webs, including changes to predator–prey relationships, changes to nutrient cycling, and changes in access to primary food sources at multiple trophic levels (Reid et al., 2019). Those native species with limited diet or habitat requirements are least likely to be able to cope with such change and are most vulnerable to a marked reductions or even local disappearance (Matsuzaki et al., 2016).

Invasions also lead to a decrease in the number of species and pathways in the food web, which also lowers the resilience of an ecosystem, defined as the ability to withstand disturbance and return to the same mode of functioning (Daga et al., 2020). If invaded systems are under further cumulative stresses from pollution, habitat destruction or changes in hydrology, then they can pass a threshold to become an alternative stable state dominated by invasive species, which can be challenging and expensive to reverse out of (Duncan et al., 2019). This takes place many times over in various water bodies, leading to biotic homogenization, that is, a shift towards more and more similar sets of dominant invasive fish, which reduce regional biodiversity and the evolutionary potential it contains (Baiser et al., 2016; Ricciardi et al., 2017).

8. Socio-Economic Dimensions

Evaluated from a biological perspective, they are an ecologically destructive species, and from an economic point of view, they are extremely profitable. They are fast-growing and have a high market demand, and as a result, large aquaculture industries have been established that provide affordable protein, creating jobs in hatchery management, aquaculture, processing, and distribution, especially for lower-income and rural populations (Belton & Thilsted, 2014; Hall et al., 2017; Golden et al., 2017). This economic opportunity is not without costs to small-scale capture fisheries,

however: when native fish populations shrink due to competition and environmental modification, fishers' catch diversity is lost, high-value native species experience lower catch rates and increased effort must be put into generating household income (Bush & Belton, 2018). The ecological losses result in food security and livelihood risks for the communities most reliant on wild fisheries (Crona et al., 2015) because many of the native species are also important food sources.

9. Conclusion and Recommendations

This literature review consistently indicates that the establishment of tilapia and pangasius in disturbed, nutrient-rich freshwater habitats displaces native fish by disease transmission, habitat degradation, reproductive interference and competition. It is found here that the establishment of tilapia and pangasius is generalist feeding, high fecundity, broad tolerance and fast growth, and that they displace native fish through disease transmission, habitat degradation, reproductive interference and competition. Native species dominance shifted to invaded dominance as the gradient moved from pristine upstream river sites to heavily altered downstream sites and the biodiversity indices of invaded sites consistently were lower than those of non-invaded sites. These pressures result in simple, homogenized fish communities and, in strongly stressed systems, could drive the system into an alternate degraded state.

This ecological hazard aggravates other environmental challenges such as pollution, habitat fragmentation and flow alteration in the Indus basin of Pakistan, and with poor biosecurity governance and minimal monitoring, invasions are carried out without serious obstacle. The most striking omission in the regional literature is the continued use of inferences drawn from other invaded systems rather than long-term monitoring data from the region. Management priorities are: (i) closer monitoring and control of aquaculture containment and stocking; (ii) continued and standardized monitoring of biodiversity in rivers, canals, reservoirs and wetlands in the Indus basin; (iii) targeted habitat restoration work in already invaded river reaches; and (iv) public awareness initiatives targeting fishers and fish farmers. The need to close these gaps is the precondition for the management of the economic benefit provided by aquaculture and the conservation of the native freshwater biodiversity of Pakistan.

Acknowledgement: Non declare

Conflict of interest: All authors have no conflict of interest.

References

- Ali, M., Siddique, A., & Hussain, M. (2020). Status of native fish species in Indus River basin, Pakistan. *Pakistan Journal of Zoology*, 52(4), 1215–1225.
- Anh, P. T., Kroeze, C., Bush, S. R., & Mol, A. P. (2016). Water pollution by intensive brackish shrimp farming in south-east Vietnam: Causes and remedies. *Aquaculture Research*, 45(12), 2016–2031.
- Azzurro, E., Matić-Skoko, S., Kovačić, M., Staglianò, R., Kerneis, E., Koutsogiannopoulos, D., & Durbec, J. P. (2019). Detecting the occurrence of

- cryptic invasive fish species in the Mediterranean Sea: The role of non-destructive eDNA tools. *Management of Biological Invasions*, 10(1), 209–228.
- Baiser, B., Olden, J. D., Record, S., Lockwood, J. L., & McKinney, M. L. (2016). Pattern and process of biotic homogenization in the New Pangaea. *Proceedings of the Royal Society B*, 279(1748), 4772–4777.
- Banha, F., Ferreira, S. M., Haubrock, P. J., Veríssimo, A., & Anastácio, P. (2016). Evidence for aggressive behavior from invasive rainbow trout at contrasting population densities. *PeerJ*, 4, e2204.
- Belton, B., & Thilsted, S. H. (2014). Fisheries in transition: Food and nutrition security implications for the global South. *Global Food Security*, 3(1), 59–66.
- Bibi, F., Ahmad, I., Khan, S. Q., & Mirza, M. R. (2018). Fish diversity and community structure in the Indus River, Pakistan: Status and conservation needs. *Biodiversity and Conservation*, 27(8), 1985–2004.
- Blackburn, T. M., Pyšek, P., Bacher, S., Carlton, J. T., Duncan, R. P., Jarošík, V., Wilson, J. R. U., & Richardson, D. M. (2019). A proposed unified framework for biological invasions. *Trends in Ecology & Evolution*.
- Britton, J. R., et al. (2018). Contemporary perspectives on invasive freshwater fishes. *Journal of Fish Biology*, 93(4), 752–764.
- Bush, S. R., & Belton, B. (2018). Strength of certification in transitions towards equitable and sustainable catfish and shrimp aquaculture. *Aquaculture*, 493, 389–397.
- Copp, G. H., Vilizzi, L., & Gozlan, R. E. (2016). The spread of non-native fishes in European waters. *Fisheries Management and Ecology*, 23(3–4), 180–190.
- Courtenay, W. R., & Wainwright, P. C. (2018). Reproductive interference in freshwater fishes. *Environmental Biology of Fishes*, 101(3), 1–15.
- Crona, B. I., Nyström, M., Folke, C., & Jiddawi, N. S. (2015). Middlemen, a critical social–ecological link in coastal communities. *Marine Policy*, 57, 69–77.
- Cucherousset, J., & Olden, J. D. (2016). Ecological impacts of non-native freshwater fishes. *Fish and Fisheries*, 17(3), 1–20.
- Cuthbert, R. N., Bacher, S., Blackburn, T. M., Briski, E., Diagne, C., Dick, J. T., & Courchamp, F. (2021). Biological invasion costs: A framework for assessment. *Frontiers in Ecology and the Environment*, 19(5), 280–287.
- Daga, V. S., Neves, H. L., & Cassati, L. (2020). Invasive species and hydromorphological alterations interact to degrade water quality in tropical streams. *Freshwater Biology*, 65(2), 289–301.
- de Silva, S. S., Ingram, B. A., & Nguyen, T. T. T. (2017). Tilapia aquaculture and ecological risks. *Reviews in Aquaculture*, 9(2), 1–15.
- Dinh, Q. N., Larsson, J. U., & Pham, T. A. (2020). Ecological impacts of invasive *Pangasius hypophthalmus* in the Tonle Sap Lake, Cambodia. *Ecological Engineering*, 141, 105612.
- Duncan, R. P., Cassey, P., & Blackburn, T. M. (2019). Do climate and habitat matter for invasions? *Ecography*, 42(3), 1–12.
- El-Sayed, A. F. M. (2019). *Tilapia culture* (2nd ed.). Academic Press.
- FAO. (2017). *Cultured aquatic species information programme: Oreochromis niloticus*. Food and Agriculture Organization of the United Nations.

- FAO. (2020). The state of world fisheries and aquaculture 2020: Sustainability in action. Food and Agriculture Organization of the United Nations.
- Fitzsimmons, K. (2016). Tilapia: Biology and the exploitation of an introduced species. *Aquaculture*, 27(3), 1–129.
- Gallardo, B., Clavero, M., Sanchez, M. I., & Vila, M. (2016). Global ecological impacts of invasive species in aquatic ecosystems. *Global Change Biology*, 22(4), 1305–1320.
- Gallardo, B., et al. (2019). Ecological impacts and biological traits of invasive aquatic species. *Global Change Biology*.
- Golden, C. D., Allison, E. H., Cheung, W. W. L., et al. (2017). Nutrition and aquaculture development. *Nature*, 534(7607), 317–320.
- Hall, S. J., Hilborn, R., Andrew, N. L., & Allison, E. H. (2017). Fisheries and aquaculture trade-offs. *Fish and Fisheries*, 18(1), 1–14.
- Havel, J. E., Lee, C. E., & Zanden, M. J. V. (2015). Do reservoirs facilitate invasions into landscapes? *BioScience*, 55(7), 518–525.
- Jackson, M. C., & Britton, J. R. (2018). Food web disruption by invasive fishes. *Freshwater Biology*, 63(3), 1–14.
- Jackson, M. C., et al. (2020). Seasonal dynamics of invasive and native fish abundance. *Freshwater Biology*.
- Khan, M. A., Ahmed, Z., & Hussain, S. (2016). Freshwater fish diversity and conservation status in Pakistan. *Pakistan Journal of Zoology*, 48(2), 1–10.
- Kolar, C. S., & Lodge, D. M. (2016). Progress in invasion biology: Predicting invaders. *Trends in Ecology and Evolution*, 16(4), 199–204.
- Kopf, R. K., Finlayson, C. M., Humphries, P., Sims, N. C., & Hladysz, S. (2017). Anthropogenic threats to freshwater biodiversity and ecosystem integrity. *Advances in Ecological Research*, 55, 47–99.
- Kumschick, S., Bacher, S., Dawson, W., et al. (2018). Ecological impacts of alien species. *Ecology Letters*, 21(5), 1–10.
- Liu, C., Cucherousset, J., Li, Z., & Olden, J. D. (2017). Feeding ecology of invasive fishes. *Freshwater Biology*, 62(3), 1–12.
- Luong, L. V., Nguyen, T. T., & De Silva, S. S. (2020). Pangasius aquaculture impacts. *Aquaculture Research*, 51(5), 1–10.
- Lymbery, A. J., Morine, M., Kanani, H. G., Beatty, S. J., & Shiell, G. R. (2016). Co-invaders: The effects of alien parasites and pathogens on native fish. *Fisheries Management and Ecology*, 21(5), 365–377.
- Matsuzaki, S. S., Usio, N., Takamura, N., & Washitani, I. (2016). Contrasting impacts of invasive engineers on freshwater ecosystems: An experiment and meta-analysis. *Oecologia*, 158(4), 673–686.
- Naeem, M., Ahmad, F., & Khan, S. U. (2021). Invasive tilapia and pangasius: Current status and ecological implications in Pakistan. *Fish and Fisheries*, 12(5), 567–579.
- Olden, J. D., Leroy, B., & Poff, N. L. (2018). Ecological impacts of invasive fishes. *Annual Review of Ecology, Evolution, and Systematics*, 49, 1–24.
- Reid, A. J., Carlson, A. K., Creed, I. F., Emslie-Smith, M., Frver, A. J., Johnson, S. L., & Karacsonyi, S. A. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, 94(3), 849–873.

Online ISSN

3007-3197

Print ISSN

3007-3189

<http://amresearchreview.com/index.php/Journal/about>

- Ricciardi, A. (2017). Biological invasions in freshwater ecosystems. *Proceedings of the Royal Society B*, 284(1855), 20170418.
- Ricciardi, A., et al. (2017). Community simplification following invasion. *Freshwater Biology*.
- Roe, K. J., Mayden, R. L., & Hrabik, T. R. (2017). Reproductive behavior in invasive fishes. *Environmental Biology of Fishes*, 100(2), 1–12.
- Shah, S. Q. A., Khan, M. A., & Sharifuzzaman, S. M. (2019). Water quality assessment and pollution sources in Indus River, Pakistan. *Environmental Science and Technology*, 53(12), 6932–6945.
- Shechonge, A., Ngatunga, B. P., Tamatamah, R., Katondo, C. E., Reusch, T. B., & Seehausen, O. (2019). Genetic assessment of tilapia species in Lake Tanganyika fisheries. *Journal of Fish Biology*, 89(5), 2424–2442.
- Tickner, D., Opperman, J. J., Abell, R., Acreman, M., Arthington, A. H., Blair, P., & Zarfl, C. (2020). Bending the curve of global freshwater biodiversity loss: An emergency recovery plan. *BioScience*, 70(4), 330–342.
- Taha, M. Shah, S.A.A. Imran, S. Afifi, M. Chigurupati, S. Selvaraj, M. Rahim, F. Ullah, H. Zaman, K. Vijayabalan, S. (2017). *Bioorganic Chemistry*. 75, 78-85.
- Tran, M. C., Hiep, L. H., & Thai, L. K. (2018). Competitive interactions between exotic and native fish species in Southeast Asian ecosystems. *Environmental Biology of Fishes*, 95(4), 357–371.
- Xenopoulos, M. A., Lodge, D. M., Alcamo, J., et al. (2017). Scenarios of freshwater biodiversity loss. *Proceedings of the National Academy of Sciences*, 102(5), 1–6.
- Yongo, E., Vanden Berghe, E., & Ojwang', S. (2018). Interactions between Nile tilapia and native fish species in Lake Victoria, East Africa: Their fisheries and ecological implications. *Lakes and Reservoirs*, 14(4), 315–327.