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Alien Invaders: A review of invasive fish species in Indian waters

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Abstract
Invasive fishes are becoming a global concern for the fisheries. These fishes are characterized by their remarkable adaptability to varying environmental conditions, high fecundity and hence pose a significant risk to native fish populations and overall ecosystem health. They often outcompete indigenous species for resources, leading to a decline in fish diversity. In India, the major rivers like Ganga, Yamuna, Brahmaputra have been dominated by invasive fishes and have displaced the local fish fauna. The main invasive fishes responsible for this ecological shift are *Cyprinus carpio*, *Oreochromis niloticus*, *Oreochromis mossambicus*, *Hypophthalmichthys nobilis*. Furthermore, challenges like climate change and project regarding interlinking of rivers further enhances the threat of increase in the distribution range of the invasive fishes. This paper discusses the impacts of these fishes on the local fish fauna, fisheries, invasion pathways and mitigation strategies.

Keywords: *Oreochromis mossambicus*, *Hypophthalmichthys nobilis*, mitigation strategies, fish fauna, fisheries, invasion pathways

1. Introduction

India is one of the 17 mega diversity countries and is home to about 10% of the global fish population. Approximately 2,500 species of native finfish have been recorded in the country, of which 1,518 species are from the marine environment, 113 from brackish waters and 877 are from freshwater habitats. Despite of the rich fish diversity, 291 exotic fish species have been introduced to the country so far [1]. These species were introduced for various reasons such as to incease the fish production, aquaculture, sports fishing etc. [2]. In addition to these, there are also some illegal and unintentional introductions. But these exotic fish species become a concern when they become invasive. According to the Convention on Biological Diversity (CBD); invasive species are those exotics which successfully outcompete the native oragnisms for food and habitat, spread though their natural environment, establish their population autonomously and also harm the ecosystem in its introduced range [3].

Invasive fishes are currently becoming a growing concern for ichthyologists and the fisheries industry. They pose a threat to the native fish diversity by competing with them for food, habitat and breeding grounds. Sometimes, these fishes also gain entry via accidental and illegal introductions. They have high fecundity, show better adaptions to the changing climate conditions, lack natural predators in the newly inhabited area due to which they tend to outcompete the native fish species [4].

The introduction of invasive fish species may also lead to severe ecological disruptions and can cause irreversible damage to native biodiversity. A striking example is the introduction of the Nile perch (*Lates niloticus*) to Lake Victoria in the 1950s, which resulted in one of the largest mass extinction events in recent history. Nile perch is a dominant predator and fed on the native ciclid population, leading to the extinction of nearly 200 endemic fish species. The cichlid species which constituted 99% of fish species diversity drastically reduced to 1% of the total fish catch after the introduction of Nile perch. This extreme loss of fish diversity disrupted the lake's food web, altered ecological dynamics, and reduced genetic diversity among surviving species. This was followed by severe socio-economic impacts, as traditional small-scale fisheries declined, affecting the livelihoods of local fishermen [5].

The give example clearly demonstrates how the introduction of an exotic species in any aquatic ecosystem without proper research can have a devestating effects not only on the native species, but also on the entire ecosystem and on the local fisheries.

Invasive species are characterized by their remarkable adaptability to varying environmental conditions (such as temperature and salinity) and high reproductive rates, pose a significant risk to native fish populations and overall ecosystem health. They often outcompete indigenous species for resources, leading to a decline in biodiversity. In India, the National Biodiversity Authority has declared 14 fish species as invasive alien species (Table 1). Among these, *Oreochromis mossambicus* (Mozambique tilapia), *Oreochromis niloticus* (Nile tilapia), *Cyprinus carpio* and *Pterygoplichthys dijunctivus* (Sailfin catfish), *Hypophthalmichthys nobilis* (Bighead carp), *Atractosteus spatula* (Alligator gar) are considered to be more destructive towards the native fish species [6, 7]. This paper highlights the devestating effects of invasive alien fish species in India, their impacts on the native fishes and steps for mitigation.

2. Status of invasion alien fishes in India

2.1 *C. carpio* (Common carp): *C. carpio* has been cultivated for over 2,500 years and is widely recognized as a food fish, sports fish and an ornamental fish. Native to Europe and Asia, this species shows faster growth and fecundity due to which it has been introduced to almost all parts of the world for aquaculture puposes [8]. It is ranked as the third most frequently introduced fish species worldwide [9]. *C. carpio* primarily feeds through benthic foraging, in which it uproots sediment in search of food. This method of feeding disturbs sediment layers at the bottom of water bodies and uproots macrophytes, altering habitats and affecting native aquatic flora. This results in declining water quality and habitat degradation in aquatic ecosystems where *C. carpio* has been introduced [10].

Table 1: Inland invasive alien fish species in India as per national biodiversity authority [1]

S. No.	Name of Taxa	English Name
1.	*Clarias gariepinus*	African catfish
2.	*Cyprinus carpio*	Common carp
3.	*Gambusia affinis*	Western Mosquito fish/Topminnow
4.	*Gambusia holbrooki*	Eastern Mosquito fish
5.	*Mylopharyngodon piceus*	Black carp
6.	*Oreochromis mossambicus*	Mozambique tilapia
7.	*Oreochromis niloticus*	Nile tilapia
8.	*Poecillia reticulata*	Guppy
9.	*Pterygoplichthys disjunctivus*	Vermiculated sailfin catfish
10.	*Pterygoplichthys multiradiatus*	Sucker mouth armored cat fish
11.	*Pterygoplichthys pardalis*	Amazon sailfin catfish
12.	*Pterygoplichthys anisitsi*	Paraná Sailfin Catfish
13.	*Pygocentrus nattereri*	Red bellied Piranha
14.	*Hypophthalmichthys nobilis*	Bighead carp

C. carpio was introduced into Indian aquatic ecosystems in 1957 for aquaculture purposes [11]. Due to similar feeding habits, *C. carpio* competes for food resources with indigenous species such as *Cirrhinus mrigala*, *Cirrhinus cirrhosa*, and *Cirrhinus reba*. For instance, its presence in River Girna and the Krishna Raja Sagar reservoir has been linked to the decline of *Cirrhinus* spp. in these aquatic bodies. Similarly, in Dal Lake and Gobind Sagar reservoir, *C. carpio* has outcompeted local snow trout populations, leading to a significant decline in their numbers [12]. In River Ganga and its associated tributaries, there has been significant increase in the population of *C. carpio* and adversly affecting the Indian major carps [7, 13]. In River Ganga, *C. carpio* has successfully established itself and forming a feral population [14].

2.2 *O. niloticus* (Nile tilapia): Genus *Oreochromis* belongs to family Cichlidae and consists of 31 species. Out of these, *O. niloticus* and *Oreochromis aureus* (Blue tilapia) have been introduced to almost 100 counties in the world and used extensively for aquaculture [15]. *O. niloticus* is a tropical species that preferably lives in shallow water. It is an omnivorous grazer that feeds on periphyton, phytoplankton, aquatic plants, small invertebrates, detritus and benthic fauna. However, invasive cichlids like *O. niloticus* are detrimental for the native fish fauna. *O. niloticus* has prolific breeding habits, shows parental care. The female incubates the eggs in her mouth and broods the fry after hatching until the yolk sac is absorbed and also multiplies every three months. It is a hardy fish and can tolerate wide range of changes in environmental factors such as salinity, dissolved oxygen and temperature [16]. The prolific breeding, parental care and tolreance to various environmental factors makes it more suitable for adaptations in variety of habitats and results competition for other local fish species. Due to these factors, *O. niloticus* is now a part of the fish fauna of the Rivers Godavari, Krishna, Cauvery and Yamuna [7]. In 2005, River Yamuna harboured only negligible quantity of *O. niloticus* and in a period of two years showed an unprecedented increase to about 3.5% of total fish species in the river [17]. Currently, *O. niloticus* have invaded the lower stretch of the river Yamuna at Prayagraj and contributing 23% of the total fish catch while the catch of Indian major carps have been drastically reduced to 2 to 6% [18]. *O. niloticus* has also showed a dominant presence in most of the river stretches of the Ganga River system and some other open water bodies located in the basin [19].

2.3 *O.mossambicus* (Mozambique tilapia): It is a cichlid native to the rivers of central and southern Africa. It is a mouth breeder and a robust fish as it can tolerate high range of temperature and salinity. Due to its aquacultural utility, it is widely introduced around the world. However, due to its robust nature, it has become invasive in many regions outside its native range [20]. It has been listed among the top 100 worst invasive species in the world [21]. *O. mossambicus* was introduced in India in 1952 aiming to fill unoccupied niches, such as ponds and reservoirs. However in a few years, the species spread all across the country and affected the fisheries of several reservoirs and lakes as in Vaigai, Krishnagiri, Amaravati, Bhavanisagar, Tirumoorthy, Uppar and Pambar reservoirs in Tamil Nadu, Walayar, Malampuzha, Pothundy, Meenkara, Chulliar and Peechi reservoirs of Kerala, Kabini reservoir of Karnataka and Jaisamand Lake of Rajasthan. The Fisheries Research Committee of India had imposed ban on its propagation in 1959 [17].

A particular case highlighting the devastating effect of *O. mossambicus* is from Lake Jaisamand. It is the second largest artifical lake in Asia located in Rajashtan, India. During 1990-91, before the introduction of *O. mossambicus*; major and minor carps contributed whooping 91% of the total catch. After the introduction of *O. mossambicus* in 90’s; the contribution of major and minor carps was restricted to just 14% while *O. mossambicus* contributed 80% of the total catch in almost just 20 years [20].

About a decade ago, *O. mossambicus* was the dominant catch in the lower stratch of River Yamuna accounting for almost 25% of the total catch [22]. However, recent reports suggest that the River Yamuna has been entirely dominated by *O. niloticus* [18]. The rise of *O. niloticus* in River Yamuna might be attributed to the facts that both *O. niloticus* and *O. mossambicus* occupy the similar niche which led to competition, faster growth rate of *O. niloticus* and possibility of hybrid formation between *O. niloticus* and *O. mossambicus* [23, 24].

2.4 *Pterygoplichthys* spp.

Species of genus *Pterygoplichthys* are popular aquarium fish species. However, as the specimens grow in size, the traders and hobbyists release them into the aquatic bodies such as ponds, lakes, rivers etc. as it becomes difficult to keep them in tanks. This aquaculture release is believed to be one of the major reasons for their introductions in the wild [25]. As a result of these unintentional introductions, species of genus *Pterygoplichthys* have been reported from various regions across India, including Kerala, Tamil Nadu, Maharashtra, Bihar, Andhra Pradesh, Uttar Pradesh, West Bengal, and the North Eastern States [7, 26, 27]. Additionally, studies have shown that they adversly affect the survival and growth of native fish fauna by either directly preying on or destroying native fish eggs, or by competing with them for food and habitat [28]. Currently, distribution of *Pterygoplichthys* spp. is limited as compared to other invasive alien fish species in India. However, future projections suggest that *Pterygoplichthys* spp. may adapt well to changing climatic conditions, leading to a substantial increase in their distribution range, especially in response to temperature changes [29].

2.5 *H. nobilis* (Bighead carp): *H. nobilis* is native to China and has been introduced in over 29 countries. It is eurythermic and adapts to a variety of water bodies like reservoirs, lakes and rivers. It is a voracious planktivorous fish that feeds especially on zooplanktons. The species can tolerate extreme environmental conditions and has high fecundity. *H. nobilis* has been introduced unofficially in India possibly from Bangladesh for aquaculture purposes. The absence of any natural predators in Indian waters has led to the establishment of *H. nobilis* in major Indian Rivers including Yamuna, Chambal, Sharada, Dewa, Gomti and Wainganga. It is known to hamper the growth of native *Labeo catla* and *Labeo rohita* due to the fact that all of them feed on zooplankton which leads to competition for food [30]. The introduction of *H. nobilis* has resulted in displacement of *L. catla*, which led to its decline in commercial catches and raising concerns about potential natural hybridization between the two species [31]. In mixed-species aquaculture systems, the presence of *H. nobilis* has been observed to negatively impact the growth performance of Indian major carps (*L. catla*, *L. rohita* and *C. mrigala*) [32]. In some Indian states like Assam and Chhattisgarh, the seed production and farming of *H. nobilis* are banned to protect native fish fauna from the risks posed by this species.

3. Discussion

The establishment of invasive fishes in the Indian waters has become a threat for the native fish fauna as well as for the aquatic ecosystems of the country. In River Ganga, invasive fishes including *C. carpio*, *O. niloticus*, *H. nobilis*, *C. gariepinus* have established completely and has displaced the Indian major carps which is evident from the catch data records [31].The introduction of invasive fishes in any aquatic body not only results in threat to native fishes but also pose a threat to the ecology of aquatic body in question. For example, tilapia prey on native fish eggs and juveniles harming the native fish populations. Also, these fishes tend to change the aquatic vegetation and sediment composition. Their feeding behaviours can disturb bottom sediments and increase turbidity in water bodies, affecting other aquatic organisms that rely on clear water and specific habitat conditions [33].

Moreover, the country's proposed river linking can also pose a threat to native and endemic fish species. The river linking will result in the unrestricted spread of invasive fishes in other water bodies. It may lead to homogenization wherein the invasive fishes which are hardy and adaptable will outcompete the native fauna. This will enhance the ongoing biodiversity crisis and negatively impact local fishing livelihoods. Hence, the proposal of connecting Indian water bodies should be taken into careful reconsideration [29].

Climate change is a critical determinant that can increase dispersal of invasive species. India ranks as the sixth most affected country globally by extreme weather events from 1993 to 2022 [34]. Climate variables notably temperature, precipitation and humidity may have significant long-term impacts on water quality and fisheries. Various impacts of the climate change such as increased temperatures and precipitation put physiological stress on the native species and disrupt their reproduction cycles. In contrast to this, invasive fishes are more hardy and tolerant towards the variables of climate change. Consequently, native fish populations, struggling to adapt to adverse climatic conditions while competing with resilient invasive species, face increasing threats to their viability [35].

In case of aquatic ecosystems, once the invasive species has entered in it and if it manages to have a self sustaining popoulation; the mitigation becomes challenging. Hence, strict rules should be implimented and enforced for introduction of any exotic fish species in any water body be it for any purpose such as commercial fisheries, sports fishing etc. Careful analysis should be done regarding the habit, habitat, ecological niche, feeding, breeding habits and the impact of the exotic fishes on the local native fish fauna before introduction. However, in some cases, there are unintentional introductions where people tend to release ornamental fishes in the wild aquatic bodies as they are unable to take care of them due to increasing size of fish (explained above for *Pterygoplichthys* spp.)**.** For such cases, the general public should be made aware of the negative impacts of such introductions on the native fish diversity.

If the fish species has already entered in the aquatic ecosystem, some ways are employed for mitigation such as physical removal, use of barriers, biocides. In addition to these, experiments also indicate that other methods such as bubble curtains, light deterrents, electric fields and carbon dioxide barriers can be employed to minimize the dispersal of invasive species [36]. In some cases, the gill net mesh size may also be increased to exert greater fishing pressure on the target invasive fish species in order to manage its abundance [16]. But these methods are only effective when the invasion has occurred in a small area. However, if the invasive fish species has already established itself in the water body, it becomes almost impossible to remove it completely [37]. Hence, rapid proactive management policies such as prediction, prevention, early detection should be applied in case of invasive species which is more effective and economic as compared to post invasion eradication methods [38]. In addition to this, the water bodies in which these invasive species have become dominant; regular seeding of local fish species should be done for stock enhancement.

Regular monitoring of the fish diversity also plays a crucial role in the early detection of invasive fishes. For this, traditional techniques such as electrofishing, use of nets can be used. However, recently environmental DNA (eDNA) metabarcoding has widely being used to assess fish diversity and for early detection of invasive fish species. It is more sensitive, accurate, cost-effective and faster technique for the detection of aquatic invasive species as compared to traditional methods [39-41]. Since the technique is comparatively new, there is a challenge of false positives and/or false negatives. Hence, there is a need to improve and optimize calibration and validation in eDNA metabarcoding procedures [42]. However a holistic approach can be employed where the traditional methods complemented with eDNA metabarcoding can significantly decrease the time taken to detect the presence of invasive fish species in any water body in order to prevent their establishment in any water body in future.

4. Conclusion

The invasive fish species are posing a serious threat on the native fish diversity as well as on the overall health of the aquatic ecosystem. As their presence lead to decline of native fish species; commercial fisheries is also negatively impacted as the native fishes are favoured by people for their good taste. Hence strict policies should be made regarding allowing the entry of any exotic fishes in Indian waters. In the aquatic bodies with dominant invasive fishes, methods should be employed to decrease their population by implement targeted fishing efforts particularly in sensitive areas or during their breeding seasons. Also, regular monitoring with traditional as well as molecular tools such as eDNA metabarcoding should be done to prevent the spread of any potential invasive fish.

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