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Review article

Impact of Exotic Fishes on Ecosystem, Economics and Management

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ABSTRACT
The introduction of exotic fishes into India began in 1863 with the introduction of trout eggs in the Nilgiri Hills and still continued for various purposes. India has abundant aquatic resources for aquaculture practices and trying to produce more fish in a shorter span of time. This has resulted in overexploitation of enormous quantities of alien invasive fishes which adversely affecting the native aquatic diversity. It is adversely affecting the ecosystem and economy of the communities dependent on it. Once the exotic fish species establishes itself, complete eradication is difficult and more expensive. The aim of this review is to collate the possible impact of exotic fishes in Indian aquatic systems and draw attention to the regulation of such alien fishes.

Key words: Exotic fishes, aquaculture, ecological impact, threats, biodiversity, management, challenges

INTRODUCTION

The introduction of exotic or invasive species causes loss of biodiversity and ecosystem destruction. India has a rich source of aquatic biodiversity and the aquatic ecosystem contains over 2317 finfishes which include fresh water (838), brakish water (113) and marine water fishes (1368) (Kapoor et al. 2002, Lakra et al. 2009). Most of the aquatic ecosystems are deteriorating rapidly because of exotic species invasions. In recent years, aquaculture practices have been rapidly growing in the developing countries (Delgado et al. 2003) to meet the food demand of a growing population, as farmers are trying to increase the production of fish and fish products, with an aim to earn more profit. To achieve their target, farmers are introducing different kinds of exotic species into India. According to available data, the introduction of exotic species into India began in the eighteenth century. The fishes for aquaculture practices, ornamental, larvicidal as well as game fishes were introduced from different countries across the world. The exotic species are capable of propagating in the given ecosystem, and they are not native to that habitat. Invasive species are fast growing, have a high reproduction rate, plasticity, tolerate varied environmental factors and use different types of food (Williams and Meffee 1998). The open water sources available in the India are rivers, lakes, canals and ponds as the ecosystem. These aquatic reservoirs are adversely affected by several factors. As per the present scenario, aquatic biodiversity is diminishing rapidly due to habitat loss, the addition of exotic species, overexploitation or the anthropogenic activities (Moyle and Moyle 1995). Other causes of the loss of aquatic biodiversity may be climate change, civilization, radiation, toxicants, pollutants etc. (Nelson 1994). It is well known that fishes determine the presence of other aquatic organisms in the ecosystem, indicating as good indicators of the water quality and functioning of the ecosystem. Moyle and Leidy (1992) stated that around 20% of the freshwater fishes of the world have already been extinct or on the verge of extinction.

According to Singh (2014), more than 320 exotic fishes have been introduced in India, which include 291 ornamental, 31 aquaculture, 4 larvicidal fish species, and some introductions are unauthorized (Table 1). Exotic fishes are used for food, game or sport fishing, controlling mosquito and ornamental aquarium keeping, molluscan control, as well as for aquatic weed control (Biju Kumar 2000). The 31 exotic species have been reported in different states from the aquaculture field (Singh and Lakra 2011) and people focused on the various adverse effects of alien fishes on the aquatic ecosystem (Singh and Lakra 2006, De Silva et al. 2006, Lakra et al. 2008). Exotic fishes have adversely affected aquatic ecosystems, therefore the invasions of alien species have to be controlled or stopped. Some exotic fishes are used for

Table 1. Exotic fishes and use or purpose of introduction

S. N.	Local Name	Scientific name	Year	Native	Use/Purpose	References
Culturable and food fish						
1	Golden carp / Crucian carp	*Carassius carassius*	1870	UK	Food and experimental uses	Biju Kumar 2000
2	Tenchor doctor carp	*Tinca tinca*	1870	UK	Food and experimental uses	Biju Kumar 2000
3	Gourami	*Osphronemus goramy*	1916	Java and Mauritius	Food, experimental use, and aquatic weed control	Biju Kumar 2000
4	Common carp	*Cyprinus carpio*	1939 1957	Sri Lanka and Thailand	Food and experimental uses	Biju Kumar 2000
5	Tilapia	*Oreochromis mossambicus*	1952	Africa	Food and experimental uses	Biju Kumar 2000
6	Grass carp	*Ctenopahryngodon idella*	1957	Japan	Food, experimental use and aquatic weed control	Biju Kumar 2000
7	Silver carp	*Hypophthalmichthys molitrix*	1959	Hongkong	Food and experimental uses	Biju Kumar 2000
8	Japani punti (Tawes)	*Puntius javanicus*	1972	Indonesia	Experimental uses	Dhara et al. 2016
9	Black carp/ Snail carp	*Mylopharyngodon piceus*	—	Eastern Asia	Food and Mollusc control	Dhara et al. 2016
10	Mud carp	*Mylopharyngodon idella*	—	Eastern Asia	Food fish	Dhara et al. 2016
11	Pangas	*Pangasian odonhypophthalmus*	1997	Vietnam	Food and Ornamental	Lakra and Singh 2010, Singh and Lakra 2012, Dhara et al. 2016
12	Pangas	*Pangasius sutchi*	1994 -1995	Thailand	Food fish	Lakra and Singh 2010, Singh and Lakra 2012
13	Climbing exotic perch	*Anabustes tudineus*	—	Vietnam	Food fish	Dhara et al. 2016
Game fish						
1	Brown trout	*Salmo trutta fario*	1863 -1900	UK	Open water reservoir	Biju Kumar 2000, Rawat et al. 2011
2	Loch leven trout	*Salmo levensis*	1863	UK	Open water reservoir	Biju Kumar 2000, Rawat et al. 2011
3	Rainbow trout	*Salmo gairdneri*	1907	Germany	Open water reservoir	Biju Kumar 2000, Rawat et al. 2011
4	Eastern Brook trout	*Salvelinus fontinalis*	1911	UK	Open water reservoir	Biju Kumar 2000, Rawat et al. 2011
5	Sock-eye salmon	*Oncorhynchus nerka*	1968	Japan	Open water reservoir	Biju Kumar 2000, Rawat et al. 2011
6	Atlantic salmon	*Salmo salar*	—	USA	Open water reservoir	Biju Kumar 2000 Rawat et al. 2011

S. N.	Local Name	Scientific name	Year	Native	Use/Purpose	References
Aquarium ornamental fishes						
1	Live bearers	27 species	—	From different countries	Aquarium fishes	Biju Kumar 2000
2	Egg layers	261 species	—	From different countries	Aquarium fishes	Biju Kumar 2000
3	Sailfin catfish	*Pterygoplichthys disjunctivus, P. anisitsi*	—	South America	Aquarium fish	Sarkar et al. 2012 Sinha et al. 2010
Larvicidal fish						
1	Guppy	*Poecilia reticulates*	1908	South America	Mosquito control	Biju Kumar 2000
2	Mosquito fish	*Gambusia holbrooki*	1928	USA and Mexico	Mosquito control	Sharma 1994, Singh 2007
3	Top minnow	*Gambusia affinis*	1928	USA and Italy	Mosquito control	Raman et al. 2013, Singh 2007
4	Nicaraguan	*Gambusia nicaraguensis*	—	USA	Mosquito control	Fink 1971
5	Gold fish	*Carassius auratus*	—	Japan	Ornamental, Mosquito control	Kamatchi 2015, Mahmoud et al. 2009
Unauthorised introductions						
1	Bighead carp	*Aristichthus nobilis*	—	—	Aquaculture	Biju Kumar 2000
2	African catfish	*Clarias gariepinus*	—	—	Aquaculture	Biju Kumar 2000
3	Nile tilapia	*Oreochromis niloticus*	—	—	Aquaculture	Biju Kumar 2000
4	Red tilapia	*Oreochromis* sp.	—	—	Aquaculture	Biju Kumar 2000
5	Red piranha	*Serrasalmus natteren*	—	—	Aquaculture	Biju Kumar 2000
Other fishes						
6	Alligator gar	*Atractosteus spatula*	—	USA and Mexico	—	Biju Kumar et al. 2019
7	Arapaima	*Arapaima gigas*	—	South America	—	Biju Kumar et al. 2019

food, biological control, and sport, while the release of fish becomes harmful to the aquatic ecosystem. The transportation and release of exotic fishes in Indian water bodies are of major concern and result in the reduction of indigenous fish species. The exotic species compete with indigenous or native fishes for shelter, food, habitat and feed upon their eggs or small-sized native fishes. In addition, alien fishes carry some diseases causing pathogens or parasites and which may lead to the loss of aquatic biodiversity (Nyman 1991). It has been suggested that the introduction of invasive fishes into ecosystems results in a disastrous impact on the aquatic biota. In addition, exotic species affect the quality of the ecosystem, biodiversity as well as socio-economic status of humans, which depend upon aquatic ecosystems for their existence (Philipp et al. 1995). Therefore, it is a major concern to check the status of exotic species, their adverse impact, and the loss of diversity of native organisms in India. The objectives of this review are to highlight the possible adverse impact of exotic fishes on native animals, ecosystems, and sustainable management of biodiversity.

EXOTIC FISHES IN INDIA

In India, more than 350 exotic fishes have been introduced for various purposes including aquaculture, games, ornamental and aquarium, mosquito control, and weed control from all over the world. Some fishes were introduced legally while some were introduced illegally.

Some dangerous carnivores are reported from the Indian water body (Table 1). The introduction of fishes increased considerably because of the high demand for a protein rich diet which leads to an increase in the production of fish in a short period. It is an important aspect to meet the food demand of the growing population of the world. Therefore, the poly-culture system of the silver carp or common carp was introduced and cultured with Indian major carps to enhance yields, the productivity of the pond which occupy the unoccupied niches in the aquaculture pond. Grass carp is commonly used in aquaculture practice to control weeds in aquatic bodies and increase the productivity of ponds. As per available information, about 600 ornamental fishes have been reported from India (Singh and Lakra 2011, Singh 2014). Researchers have reported the constructive impact of ornamental alien fish species for economic and commercial importance. For the control and overproduction of alien fishes, the mixed-sex culture of Tilapia and *Clarias gariepinus* is used. Some fishes are larvicidal and feed on mosquito larvae, used as a biological natural method to control mosquito-borne diseases (Collins 2000). Certain pesticides were used to regulate mosquito growth and reproduction (Collins 2000, Milam et al. 2000). The adverse effect of insecticides used for mosquito control has been reported earlier. Thus, interestingly the plantation of predator fishes in the ecosystem can provide the natural biological method for pest control (Chandra et al. 2008). In a developing country, there is a dominant impact of mosquito-born diseases and a major problem to cope with such issues. In earlier years, fishes were used as a tool to control mosquito larvae in the ponds (Floor 2006, Walker and Lynch 2007) and used as a traditional method. Although, several positive impacts of exotic fishes were reported but the adverse impact on the aquatic system should not be ignored concerning loss of diversity and destruction of the ecosystem. The change in habitat structure, abiotic, biotic components, physicochemical properties of water and soil are associated with alien species that may cause loss of species.

Impact of exotic fishes on ecosystem

Habitat destruction is a primary cause of the reduction of biodiversity and invasive alien fishes are the second major cause of the decline of biodiversity (Raghubanshi et al. 2005). Exotic fishes are sturdy fishes, feeding voraciously and they adapts to any adverse condition as well their rate of reproduction is high. Non-native species occupy the large water body in a short time and fight for food and shelter with native species. It results in biodiversity loss, reduction of native species, and extinction of local diversity due to changes in hydrology and ecosystem functioning. Uncontrolled import of ornamental fishes resulted in more exotic fishes in the Indian freshwater bodies such as the Chalakudy River (Sandilyan 2016). The Chalakudy River is the hot spot of biodiversity in the Western Ghat region with more than 27 ornamental fishes. The exotic fishes have more stronger ability to adapt, a high breeding ability and which results in dangerous conditions for the indigenous species (Sandilyan 2016).

The introduction of exotic fishes induces more stress on the aquatic ecosystem and harms the indigenous fishes has been reported earlier in response to ecological, biological, diversity, and fish health. Exotic fishes were intentionally introduced and cultured because of their fast growth rate, adaptation ability to tolerate environmental changes, and disease resistance ability (Chen et al. 2007, Lin et al. 2015). These alien or exotic invasive fishes may accidentally escape from the aquaculture ponds and increase their population in the open natural ecosystems (Xu et al. 2006a). Furthermore, the introduction of non-native or exotic fishes that induce adverse impacts on the ecosystem via decreasing native species, suppress growth rate, and reduction of food availability by modification in the food web in the aquatic ecosystem (Britton et al. 2010). Therefore, exotic species threaten the local native fish through competition in several aspects and result in the reduction of native species (Xia et al. 2019, Joshi et al. 2021). The exotic species invasion is responsible for causing dramatic devastation to the aquatic ecosystem (Liang et al. 2006) as could be seen from the invasion of *Arapaima gigas* and *Atractosteus spatula* in aquatic systems of Kerela (Biju Kumar et al. 2019) and from Bolivia. The carnivorous Alligator gar (*A. spatula*) has been recently reported from Pawan Dam, Pune (Anonymous 2018), Ganga river system (Manna et al. 2021) and Panchganga River Kolhapur (Anonymous 2022). The plantation of alien fish causes, approximately 80% loss of endangered species in the world due to habitat or food competition or predation (Pimentel et al. 2005). The introduction of the amethyst gem clam (*Gemma gemma*) was conducted in California's Bodega Harbor from the United States of America and found in small quantities but never affect

Table 2. Impact of exotic fishes

Factors affected	Impacts
1. Habitat structure	Loss of native habitat
	Loss of ecosystem character
	Loss of ecosystem health and productivity
2. Individual impact	Changes in behaviour
	Affect the morphology
	Reduce vital rates
3. Change in water quality	Reduction in dissolve oxygen levels
	Mineral concentration changes
	Changes in organic matter
	Increase water turbidity
	Make poor quality of water
4. Community impact	Loss of native biodiversity
	Loss of food tropic levels and their interactions
	Change in local biomass
	Loss of food web and food chain
5. Species population	Loss of species by predation
	Loss of species by food competition
	Loss of species by space and shelter
	Relocation or migration of fishes
	Increase disease risk
	Reduction in reproduction
	Changes in behavioural pattern
	Growth rate reduced
	Increased mortality in fishes
6. Genetic impact	Exploitation or loss of native genetic diversity

the native calm (*Nutricila* spp.) species. Furthermore, the introduction of European green crab (*Carcinus maenas*) caused the reduction of native clams (Grosholz 2005). In the Mediterranean region, the cause of the loss of biological diversity in freshwater ecosystems or habitats is exotic species (Cuttelod et al. 2008, Medail and Quezel 1999). This suggests that the introduction of exotic species interact with other species and affects the native species. Exotic or alien species like *Oreochromis mossambicus, O. niloticus, Cyprinus carpio*, Golden carp, Silver carp, etc. occurred in the open water bodies where drastic reduction in the occurrence and the number of the indigenous native species was reported. It has been reported that in the presence of guppy fishes, the density of the *Rivilus hartii* population reduced drastically, may be because of competitive or predatory interaction (Walsh et al. 2011). Furthermore, the decline of *R. hartii* is because of guppy predation on young ones. Thus, it is an alarming call to protect, conserve and save native species. According to ISAC of the United States of America, the population of native species significantly decreases (Anonymous 2006). In addition, there are drastic modifications in the animal and plant communities, and ecological processes like the food chain, and food web of native species which affect human health and survival (Table 2).

The most popular fishes like *Cyprinus carpio* and *Clarius gariepinus* adapt to any water body and affect the local fish population through overcrowding, replacement, or competition (Castaldelli et al. 2013, Corfield et al. 2008). The benthivores alien fishes induce a negative impact on all native fishes through predation, food competition, aggregation as well as habitat change (Arthington 1991). It has been reported that alien fishes directly affect the quality of water through a string of mud which increases the water turbidity of water (Boyd et al. 2002, Volkenbom et al. 2007, Badiou et al. 2011, Kloskowski 2011, Kadye 2011, Pascal and Goldsborough 2015). The population of zooplankton, micro, and macroinvertebrates are adversely affected by the common carp and exotic catfishes (Badiou et al. 2011, Weber and Brown 2011, Kadye 2011) (Fig. 1). Invasive alien species interact with native species and cause severe impacts on native species. The native gene erosion may happen through hybridization that results in sterile offspring and reduced population size. An example of the hybridization was found in exotic rainbow trout (*Oncorhynchus mykiss)* and native trout (cutthroat trout) (Campton 1987) and between invasive alien mallard ducks (*Anas platyrhynchos*) etc. (Rhymer and Simberloff 1996). Thus, exotic fishes may be an evolutionary threat to biodiversity. In summary, as per the study on the aquatic ecosystem, the diversity of native fishes is declining day by day and some species are becoming extinct or under verse of endanger of extinction. Along with the other causes, invasive species may be one of the major causes of the loss of diversity of native

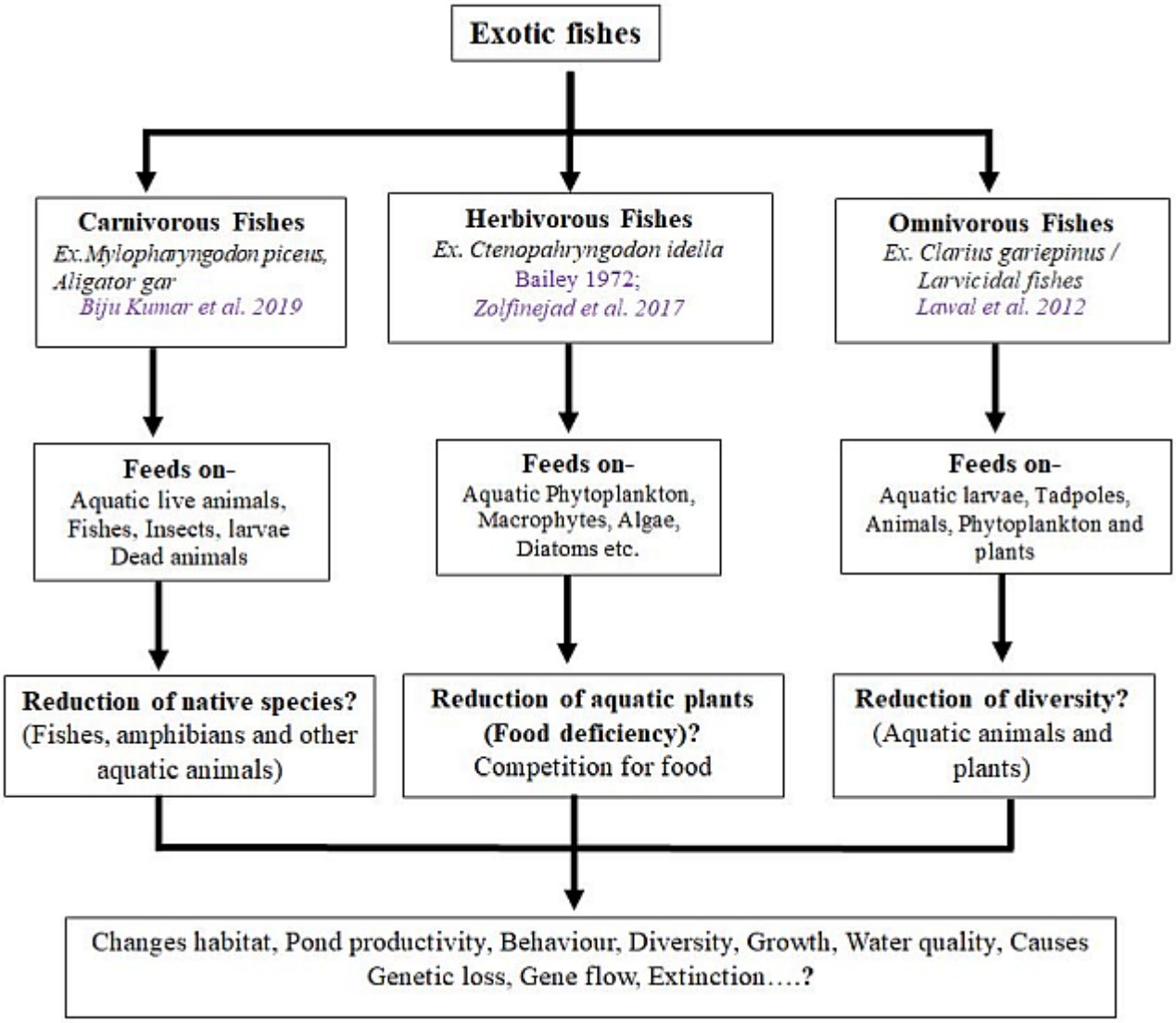

Figure 1. Exotic fishes may induce the possible impacts on the native species, habitat and aquatic ecosystem

species (Table 2).

Economics impact of exotic fishes

India has great aquatic resources to culture and market the native fishes. The exotic fishes cause enormous ecological as well as ecological loss (Xu et al. 2006a). Recently, with the invasion of exotic fishes, the minds have diverted and focused on exotic fishes rearing and cultivation because of their high growth rate, disease resistance, high reproduction rate, and better adaptation. Thus, large amounts of fish meat can be produced in a short time and space. The alien fished may not be preferred as good quality food and thus have low commercial value. The exotic species enhance fishing and result in a decrease in fishermen's income because of the low price of exotic fishes (Xia et al. 2019). Therefore, the fisherman has to catch more fishes to increase their income. Recently ornamental and aquarium fishes import trade and their introduction into the ecosystem become serious issues to the native aquatic biodiversity. During aquaculture practice, the requirement of eradication of exotic fish may cause economic loss and increase maintenance costs. Huge annual economic losses were reported due to exotic fishes in the United States and China (Pimentel et al. 2005, Xu et al. 2006b). Exotic fishes not only affect the ecosystem's health but directly or indirectly affect human health. The bacteria cause adverse diseases in the fishes and also cause health problem in human (Shotts 1987) that results in the loss of human health. Therefore, it has to be undertaken that the alien species directly or indirectly affect the economics of the people.

Management challenges

There are several challenges in the management of alien species. In the Indian aquaculture practices, a huge number of invasive fishes like Grass carp, Silver carp, Crucian carp, Tilapia has been introduced and widely used. It is necessary for the fulfilment of the food protein demand of the growing population. Therefore, the complete prohibition of exotic fishes may directly affect the economics of the farmers, people and society. Exotic fish eradication from the ecosystem and management is a very tedious process. It requires more manpower, economic investment and infrastructure. Therefore, continuous monitoring and eradication of alien fishes may become a difficult task. The control and monitoring of invasive fishes is a very problematic issue because these fishes are hardy, faster growing, have easy adaptation, and have a high rate of reproduction. Thus, the management of fishes at the ground level is most challenging. The management of exotic fishes should be monitored via the import, export, or transportation of fishes used for food, aquaculture practice, ornamental, etc. It is to be monitored through release in an open water body or accidental release, etc. Otherwise, the alien fishes damage the ecosystem health and demolish the freshwater native aquatic biodiversity. For effective control, some important factors should be undertaken for the control of the release of invasive fish in inland water. There should be a frame and implementation of strict laws, and rules to check the import of exotic species. Unauthorized import, transportation, and culture of exotic fishers should be banned and strict action should be taken. Strong regulations should be framed against the release of exotic fishes in open water bodies and adverse action should be taken. Controlled monitoring of transport, the introduction of exotic fishes, and their removal should be adopted. For effective control of the introduction of exotic species, the sensitization and awareness program should be conducted for people and students through seminar, discussions, conferences, group rallies, and display of posters and wallpapers at different public places to emphasize the aquatic ecological ecosystem destruction and their adverse impacts on biodiversity. Create awareness about the impact of exotic species on the ecosystem by creating short films, short movies, short cartoon movies, and advertisements using an entertainment system.

CONCLUSION

The exotic fish invasion of the freshwater body is a global issue. There is an accidental escape of fishes into the open water body results in easy establishment and adaptation. It may be because of their hardy, strong, omnivorous nature, modification in feeding habitat, faster-growing ability, high breeding rate, easy coping with the change of environment, etc. This attributes to the change in aquatic ecosystem biotic structure. Exotic fishes exert not only a deleterious effect on native species but also, affect the ecological, genetic, economic, and health. Therefore, it is an alarming stage and needs to takes immediate action to prevent the import and escape of alien species into the open aquatic ecosystem to conserve native species, ecosystem health, and sustainability.

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