Journal of Aquatic Biology & Fisheries, Vol. 2(1) 2014: 32-41

EMERGING ALIEN SPECIES IN INDIAN AQUACULTURE: PROSPECTS AND THREATS

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Abstract: The collected information on alien fish species revealed presence of 31 fish species introduced in the country for aquaculture purpose while over 600 varieties of ornamental aquarium fishes. Many of them were illegally introduced and their historical information was not available. In this paper, we have generated scientific information on the distribution of alien fish species in different natural aquatic bodies and assessed their adverse ecological consequences such as decline of local fish species, competition with local species for food and feeding, space and spawning; threats to species integrity and ecosystem. A number of invasions of freshwater exotic fishes have taken place into India over the past decade and adversely affected the fish biodiversity. Many more changes are predictable to occur with the expected climate change invading newer areas and ecosystems. The estimated annual average production of alien species fit for human consumption amounts to around 18.2 to 34.5% of the annual average production of marketable fish cultures in India. A significant negative impact of the introduced species on native ichthyofauna has been ascertained as regards to its ecological, biological characteristics, biodiversity and health. Considered a typical invasive alien species, *Oreochromis mossambicus, O. niloticus and Cyprinus carpio* heavily depressed the occurrence and numbers of indigenous populations and also contributed to the declined fishery of native cyprinid fish species in several natural aquatic bodies of the country.

Key words: Alien species, invasion, biodiversity loss, sustainability, management

INTRODUCTION

Introductions of alien fish species are an important part of human activities concerning aquatic ecosystems (Garcia-Berthou, 2007). In India, over 300 alien fish species including 291 ornamental species, 31 aquaculture species and 3 larvicidal fishes are recorded.These introductions arehuman mediated, which may be intentional or unintentional. Both types of introductions can cause bioinvasions i.e.,introductions assisted by humans and natural range expansions. Similarly, the ornamental fish trade in India is also dominated mainly by the presence of over 500 alien fish variety such as goldfish, angel, guppy, swordtail, oscar, platy, cichlids, tetras, gouramis, sucker mouths, pacu etc. and they have been introduced from different parts of world, mainly from Asia. At present, alien species are considered one of the major causes of erosion or devastation of the native fish biodiversity in freshwater ecosystems (Lakra *et al.,* 2008; Garcia-Berthou *et al.,* 2005, Garcia-Berthou 2007; DeSilva *et al.*, 2009; Singh and Lakra, 2011). Most of the intentional introductions aimed to bring benefits to fishery management, aquaculture and fishpond production or in the case of natural ecosystems, by a need to fill vacant niches, to increase production and to provide new objects for sport fishing and ornamental fish (Lakra *et al.* 2008; Singh and Lakra, 2011). In the past, no heed was paid to the risks of introductions or the latter were not thoroughly premeditated, often because the negative impacts of the alien fish species became apparent only some time after the alien

species were introduced and established in the ecosystem.

In connection with the problem of conserving and protecting the biodiversity of native ichthyofaunas, specific attention has been paid to the impact of alien taxa on native fish species (Berthou-Garcia *et al.,* 2005; Lakra *et al.,*2008; Singh *et al.,*2010). The introduction of alien fishes, connected with the aspect of biological invasion, is among other grave topics in a number of papers (Garcia-Berthou *et al.,*2005; Garcia-Berthou, 2007; Singh and Lakra, 2011). The problem of alien species has become one of global importance, particularly as a result of the direct or indirect connection of hydrological systems (Garcia-Berthou, 2007).

Recently, researchers have been focusing on the global aspects and evaluations of introducing alien species, analyzing and attempting to define the *et al.,* 2005; Moyle and Marchetti, 2006; Riberio *et al.,* 2008; DeSilva *et al.,* 2009). Based on such analyses, one can predict, with considerable safety, the successful invasions of naturalized alien species, yet it is still impracticable to control or stop them (Moyle and Marchetti, 2006; Riberio *et al.,* 2008). Vigorous measures, effective in spatially limited areas only (Meronek *et al.,*1996), are not permissible in view of the present aspects of nature conservation. The so-called biological control (predation, competition for space for food and breeding, infestation with parasites and/ or pathogens) of established alien species is problematical (Thresher , 2008; Singh and Lakra, 2011). Therefore, the rather negative attitude towards alien species is accompanied by a sceptical attitude towards possibly successful measures to be taken against established alien species (Garcia-Berthou *et al.,*2005, Thresher, 2008).

The introductions of alien fish species have been important both in their positive and negative consequences for fishery management as well as for the native components of the ichthyofauna of natural ecosystems (DeSilva *et al.,* 2009). Several summarizing papers have been published on the introduction of fishes into the waters (Garcia-Berthou *et al.,*2005; Garcia-Berthou, 2007; Thresher, 2008; Lakra *et al.,*2008; Singh *et al.,*2010; Singh and Lakra, 2011). However, they are mainly aimed at evaluations of the success of the particular attempts. In the present contribution, an overall assessment of introductions of alien fish species used in aquaculture has been attempted. This study also reviews fish introductions and, at the same time, attempts to evaluate the positive and negative consequences of such activities in the country. The term "introduction" or "alien" in this paperhas been used to denote a release of an alien fish taxon outside its native geographic region. The present paper is based, partly on published papers quoted but mainly on our own published, unpublished and data obtained from our research work on alien fish species over the past decade. The complete scientific names of alien species have been unified according to Fish Base (Froeseand Pauly, 2009) and Eschmeyer (2010), higher taxa (families) according to Nelson (2006).

OCCURRENCES AND DISTRIBUTION OF EXOTICS IN OPEN WATERS

While there were 31 alien fish species recorded from aquaculture in India (Singh and Lakra, 2011), culture of some species such as *Pangasia nodonhypoththalmus, Oreochromis niloticus, Piaractus brachypomus, Aristichtys nobilis, Onchorhynchys mykiss, Clarias gariepinus* and *Litopenaeus vannamei* picked up during recent years only. The fish diversity of India is represented by the presence of about 120 commercially important fish species of which 60 species are widely distributed in most of the water bodies (Lakra *et al.* 2009). The important ones are *Catla catla, Labeo rohita, Cirrhinus mrigala, L. calbasu, L. dyocheilus, Wallago attu, Chitala chitala, Tor tor, T. putitora, Clarias batrachus, Heteropneustes fossilis, Channa marulius, C striatus, Anguilla bengalensis, A. bicolour, Mugil cephalus, Lates calcarifer, Rhinomugil corsula and Chanos chanos.* Besides these prawns *Macrobrachium rosenbergii, M. malcolmsonii* and shrimps *Penaeus monodon, P. indicus P. merguensis* are also present. Some of

the important endemic cultivable food fishes of Western Ghats are *Labeo dussumeri, Horabagrus brachysoma, Etroplus suratensis, Gonoproctopterus curmuca, Tor khudree, Labeo fimbriatus, Punitus pulchellus.* Similarly in the north eastern areas, *Neolissocheilus hexagonolepis, Cyprinus semiplotum, Chagunius chagunius, Osteobrama belangeri, Channa berca* are some of the important endemic food fishes of this region. However, there has been intensive aquaculture diversification using alien fish species. The estimated annual average production of alien species fit for human consumption amounts to around 18.2 to 34.5% of the annual average production of marketable fish cultures in India. Many of the cultured alien species have been deliberately or inadvertently released and are now appearing in natural aquatic bodies. We have examined the invasion of alien fishes in aquatic systems such as rivers lakes, reservoirs and wetlands that differed broadly in locations and fish diversity. The exotic species were classified as invasive for those that formed reproducing populations and that were present in the system for the last more than five years. Examination of fishes for reproductive stages was done to ascertain their breeding status and the same was reconfirmed with the captured alien fishes of different sizes i.e., fry, fingerlings, growing, maturing and mature fishes.The impacts of introduced fishes available in natural aquatic bodies were assessed by the developed protocol in the laboratory for the Fish Invasiveness Screening Test (FIST**)** and also on the basis of the ability of the exotic fish to reproduce naturally, dispersal ability (propagule pressure), fast growth, phenotypic plasticity (tolerance of range of salinity and temperature), ability to live off a wide range of food types and other successful invasive characters (Singh and Lakra, 2011). The Impact assessment studies were carried-out in the Yamuna, Ganga, Periyar rivers, back waters of Kerala, Jaiselmer lake (Rajasthan), Ramgarhlake (Uttar Pradesh.) and Kolleru lake (Andhra Pradesh). Ecological impact assessment of *Oreochromis mossambicus*, *O. niloticus*, *Pangasianodon hypophthalamus*, *Litopenaeus vannamei*, *Clarias gariepinus*, *Cyprinus carpio, Hypophthalmichthys molitrix, Ctenopharyngodon idella, Aristichthys nobilis* and *Piaractus brachypomus* commonly occurring in aquaculture and breeding was attempted. The collected information on alien fish species reveals presence of twelve introduced fish species under present commonly under aquaculture in the country. Many of them are illegally introduced and their historical information such as the source, place and period of their introduction is unknown. Some of these introduced fishes are now found in different inland water bodies. Some of the exotic fishes such as *P. hypophthalmus*and *Piaractus brachypomus* have been used both for food as well as ornamental purpose and hence their possible release into natural habitats was doubled on account of high propagule pressure. We have captured some live specimens of piranha *Pygocentrus nattereri* and pacu *P. brachypomus* from Periyar river of Kerala and from Dimbhe reservoir near Pune, Maharashtra. There were incidences of some people bitten when they entered into the reservoir for their day to day work. Two highly invasive fish species *Pterygoplichthys dijunctivus* and *P. pardalis*were recorded to breed in large number in wetlands of West Bengal where thousands of live specimens were captured. They were also captured from lakes, rivers and reservoirs in Andhra Pradesh, West Bengal, Bihar and Uttar Pradesh.

The detailed information on the present distribution of alien species in natural waters is synthesized, summarised and presented (Table 1).

Table 1. Spread and status of exotic fish species in Indian open-waters

Exotic fish species	Status	Occurrences in natural water bodies			
		Rivers	Reservoirs	Lakes	Wetlands
Cyprinus carpio (C. carpio communis, C. carpio specularis, C. carpio nudus)	Introduced for broadening the species spectrum in aquaculture	Ganga, Yamuna, Godavari, Gomti Damodar, Ghaghra, Rapti, Panba, Tons and many others	Most of the reservoirs	Most of the freshwater lakes	Bihar, West Bengal, Assam, Uttar Pradesh
Hypophthalmi-chthys moltrix	Do	Ganga, Yamuna, Sutlej, Mahanadi, Pumba, Gomti, Tons	Some reservoirs in Himachal Pradesh, Madhya Pradesh, Kerala, Uttar Pradesh	Some freshwater lakes in Himachal Pradesh, Madhya Pradesh, Uttar Pradesh, Uttarakha-nd	Wetlands of Bihar, West Bengal, Assam, Uttar Pradesh
Ctenopharyng-odon idella	Do	Pumba, Gomti, Yamuna, Ganga	Some reservoirs	Some freshwater lakes in north India	Wetlands of Bihar, West Bengal, Assam, Uttar Pradesh
Aristichthys nobilis	Illegally introduced but widely cultivated. It is a banned species	Yamuna, Ghaghra, Rapti, Gomti, Ganga, Sarayu	Uttar Pradesh	Some freshwater lakes in Uttar Pradesh, Madhya Pradesh, Karnataka	Wetlands of Bihar, West Bengal, Assam, Uttar Pradesh
Clarias gariepinus	Illegally introduced but widely cultivated. It is a banned species	Yamuna, Gomti, Godavari, Pamba, Ganga	Karnataka, Uttar Pradesh, Andhra Pradesh	Some lakes in Andhra Pradesh, Karnataka Kerala, Meghalaya, Uttar Pradesh	West Bengal, Bihar, Andhra Pradesh, Uttar Pradesh

Oreochromis massambicus	A nuisance species widely distributed	Yamuna, Subarnarekha, Cauvery, Damodar, Periyar, Ken and Betwa	Most of the reservoirs in Tamil Nadu and some reservoirs Karnataka and Kerala, Jaisamundsagar (Rajasthan), Getalsud reservoir (Jharkhan)	Some lakes in West Bengal, Assam and Madhya Pradesh	West Bengal and Assam
O. niloticus	Introduced for aquaculture	Yamuna, Ganga Subarnarekha, Cauvery, Damodar, Periyar, Ken and Betwa	Many reservoirs in West Bengal, Bihar, Madhya Pradesh and Uttar Pradesh	Some lakes in West Bengal, Assam and Madhya Pradesh	West Bengal, Biharand Assam
Pangasianodon hypophthalmus	Considered potential species for aquaculture promotion	Churni river, Godavari, Krishna	No report	Some lakes in Andhra Pradesh and Kerala	West Bengal
Oncorhynchus mykiss	A good candidate species of aquaculture in hills	Pamba, Periyar, Bharathapuzha, Bhilangana, Asi Ganga		Some lakes in upland waters	-
Salmo trutta fario	A very good candidate species for aquaculture in hills	Beas Sutlej, Asi Ganga		Some lakes in upland waters	-
Piaractus brachypomus	Unauthorized culture and distributed in many states including coastal areas	Periyar river Kerala	Maharashtra	-	West Bengal and Andhra Pradesh
Pterygoplichthys spp. (*P. pardalis, P. disjuntivus*)	Unauthorized introduction and distributed widely in aquariums	Ganga and Gomti rivers	-	-	West Bengal and Andhra Pradesh

Pygocentrus naterreri	Unauthorized introduction for aquarium purpose and a banned species	Periyar	Maharashtra	Kerala	-

In addition to different alien fish species, we have also recorded presence of various hybrids of alien fishes such as hybrid African catfish, bighead, tilapia, trout and even pacu have been identified which are available in aquaculture. Hybrid magur and bighead are very common at farms due to its fast growing habits and tolerance to harsh environmental conditions. Hybrids between the indigenous and African catfish are being produced in the hatcheries in Bangladesh (Rahman *et al.*,1995; Sahoo *et al.,* 2003; Singh and Lakra, 2011) and the seed smuggled into the bordering north-eastern States as well as Assam and West Bengal and as far as Bihar and forms the basis of a flourishing trade of alien catfish. This obnoxious predator, perhaps far moreinimical to the indigenous species, *C. gariepinus* has now gained an unsolicited entry into the mighty rivers like the Ganga, Yamuna, Sutlej and Godavari that are the pride of India for its precious and specificgene pool. Detailed information on available hybrids and their aquaculture productions in different countries have been tabulated and presented (Table 2).

Table2. Presence of hybrids in aquaculture and their productions (FAO, 2012)

Sl. No.	Hybrids under Aquaculture	Country	Production (tones)
1	Blue & Nile tilapia hybrid (*Oreochromis aureus* x *O. niloticus)*	China and Panama	333 300
2	*Clarias* catfish hybrid (*Clarias gariepinus* x *C. macrocephalus*)	Thailand, Bangladesh, Nepal, India	116 900
3	Tambacu" hybrid (*Piaractus mesopotamicus* x *Colossoma macropomum*)	Brazil, Vietnam, Peru, Bangladesh	21 600
4	Tambatinga" hybrid (Colossoma macropomum x Piaractus brachypomus)	Brazil, Bangladesh	4 900
5	Striped bass hybrid (*Morone chrysops* x *M. saxatilis*	US, Italy and Israel	4 200
6	Splake Trout (hybrid between lake trout and brook trout)	J & K	Not known
7	Hybrids of bighead & Silver carp (*A.nobilis x H. molitrix)*	Bangladesh, Nepal, India	Not known

IMPACT OF ALIEN FISH SPECIES ON FISH BIODIVERSITY

There is an alarming increase in the number of exotic fish species being detected in the rivers, lakes and reservoirs in recent years (Figure 1). The exotic fishes moved into open waters inadvertently or due to unawareness or lack of knowledge of the aquaculturists and farmers. The impact of such escapee fishes have been assessed and found to cause ecological problems in several natural aquatic systems including the Ganga River, the largest in the country. Ecological risks have been mainly caused by alien species that have become fully established and acclimatized in natural ecosystems and show naturally reproducing populations. In suitable conditions, such species produce abundant populations.

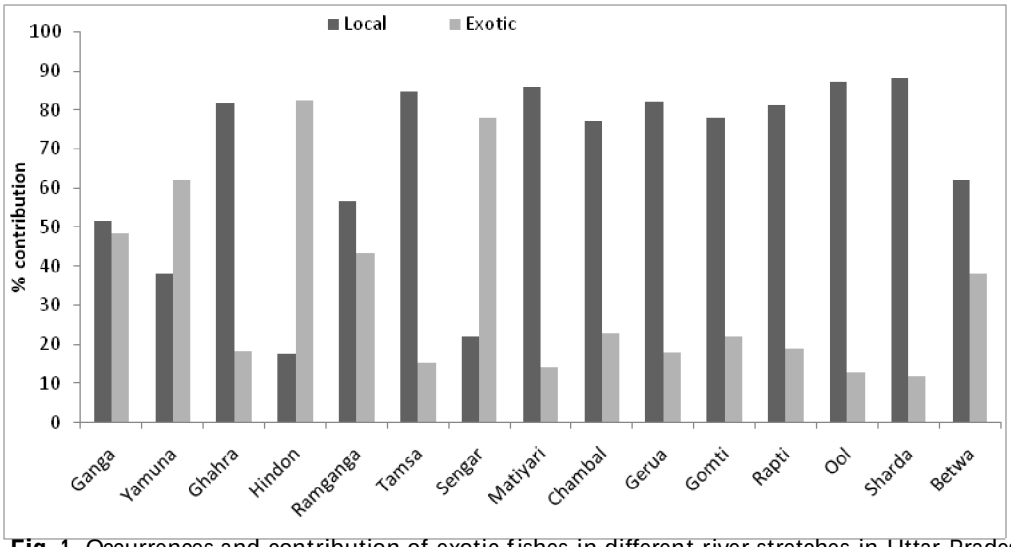

Fig. 1. Occurrences and contribution of exotic fishes in different river stretches in Uttar Pradesh.

Oreochromis niloticus and Cyprinus carpio, a known invasive fish has been found to displace Indian major carps from Ganga and Yamuna rivers, and alsofrom natural aquatic bodies of the country. Thprolific breeding habit of tilapia andparentalcare helped it to multiply every three months causing space overlap for other local species. The fish constitutesnow a part of the fish fauna of the Godavari, Krishna, the Cauvery, the Yamuna and the Ganga rivers where all stages of its lifecycleare available. Both *Cyprinus carpio* and *Oreochromis niloticus* have been found to dominate in the commercial fishery in the Ganga River during recent years. The catch of local fishes particularly Indian major carps declined by 24.56% at Allahabad and Varanasi in the State of Uttar Pradesh while the catch of exotic fishes increased over 115.80% during 2010. Present commercial fishery of Yamuna and Ganga rivers in the State of Uttar Pradesh is now saturated with the presence of exotic fishes particularly *Cyprinus carpio, Oreochromis niloticus* and also few specimens of *Clarias garipinus, Aristichthys nobilis, Hypophthalmichthys molitrix* and *Ctenopharyngodon idella*. The frequency occurrence of different sizes and the proportion of male females in different catches reveals that the existing populations had sufficient number of both the sexes to so that to have every possibility to breed naturally and form feral population. This wsa further confirmed by reproductive phasing of the fish. Distribution and abundance of exotic fishes and native fishes has also been mapped for the Yamuna River using geographical information system (GIS) tools (Singh *et al.,* 2010). The calculated Pearson's correlation coefficient for yield of alien fish species with local fish groups in the Ganga River shows that there has been a positive correlation of common carp (0.757) and tilapia (0.712) with Indian major carps. The alien carps have also been positively correlated (0.631) with Indian major carps. However, in case of local catfishes the correlation coefficient was poor for all feral alien fishes. The Pearson's coefficient correlation for the miscellaneous local fish species showed positive correlation particularly with common carp and tilapia.

Sutchi catfish *Pangasianodon hypophthalamus,* African catfish *Clarias gariepinus* and pacu *Piaractus brachypomus* are the recent aquaculture activities. It is now understood that over 0.8 million tonnes of *P. hypophthalmus,* 0.15 million tonnes of *L. vannamei*, and 0.1 million tonnes of pacu are produced in the country. Alien catfish cultureis rapidly spreading using animal waste as cheap feed. The animal waste recycled

aquaculture of alien catfishes is now common into all agro-climatic regions of the country. African catfish *C. gariepinus* tolerated vide range of temperature (12-36 ± 1°C) as well as salinity (<14 ppt), which facilitated its wider spread in the country. It was found in the coastal areas, freshwater ponds, tanks, lakes, reservoirs and even in some rivers such as Godavari, Yamuna, Gomti and now in the Ganga River as well.

Amongst the prawn and shrimp culture, *Macrobrachiu rosenbergii* and *Penaeus monodon* were the locally important cultivable species however, aquaculture of *Litopenaeus vannamei* recently attracted farmers in India because of its fast growth, low incidence of native diseases, availability of domesticated strains and also being motivated by international market. Ministry of Agriculture had given permission for pilot scale culture of *Litopenaeus vannamei* which has increased demand and production has gone up.The introduction of *L vannamei*has been done largely by the private sector, due to the perceived benefits offered by the introduced species. The current perceptions that: *L vannamei*are more disease resistant than the indigenous species (*P monodon*), specific pathogen free (SPF) and specific pathogen resistant (SPR) brood stock have been developed that are free from disease, and that they are more able to tolerate high density and low salinity which are the main driving forces behind their introduction. Whether these perceived benefits are true or not is often debatable, particularly when Asian shrimp farmers are struggling to make money using their traditional native species. Importing SPF brood stock and producing disease-free seed in bio-secured hatcheries has been considered as a workable modality. Even shrimp species

DISCUSSION

Although major introductions of alien fishes into the country outside their natural range are a relatively a recent phenomenon (Singh and Lakra, 2011). Alien species particularly Chinese carp excluding bighead and common carp have played an important part in the development of aquaculture. However, these species from aquaculture facilities have escaped and colonized in natural waters. In addition, inadvertent releases of African catfish *C. gariepinus* which is relatively large, voracious and highly carnivorous is capable of exerting direct adverse impacts on a wide range of native fish population. In this study, we have found increased incidence and occurrences of alien species in several river stretches, reservoirs, lakes and wetlands which have been considered serious in view of sustainability of local fish diversity (Singh *et al.,*2010; Singh and Lakra, 2011). The riverine resources of the country are currently experiencing an alarming decline in fish biodiversity due to several environmental factors in general and invasion of many relatively new alien species in particular (Singh and Lakra, 2011; Sarkar*et al.,*2012). Since alien fishes are dominant in characters and aggressive in behaviour, they have potential to extirpate the local fish species. Recent invasion of tilapiaand common carp has increasingly taken-over at many locations contributing substantially to the fishery of many river stretches and streams eliminating the catch of locally commercial important species particularly Indian major carps (Singh et al. 2010). Similar scenario is also emerging in some lakes, wetland even reservoirs which are also getting adversely affected.

Further, we have also recorded the occurrences of some aquarium fish species such as *Pterigoplichthys pardalis, P. disjunctivus, Gambusia affinis, Poecilia reticula, Xiphophorus maculats*. Such unintentional releases are unsafe for fish biodiversity. Unless stringent measures are taken to monitor the aquarium fish trade and the accidental release of exotic species into our waters; streams and lakes will soon emerge as breeding grounds for several invasive fish that will eventually wipe out our native freshwater fishes. The Convention on International Trade in Endangered Species (CITES) falls short of protecting aquatic habitats from invasions because it deals only with the trade in listed endangered and threatened species. However, under Convention on Biological Diversity (CBD), it is the responsibility of each nation and the state

to prevent spread of any invasive alien species which is harmful to the fish biodiversity and aquatic ecosystem. The aquarium trade industry is spreading fast, therefore, it is essential for educating buyers, sellers, and the public, certifying stock, and preventing species from being released. In addition, certification that aquatic ornamental cultivators and large-scale aquariums sterilize their outflows and take active steps to prevent the accidental release of species is essential. Educating both retailers and hobbyists about invasive species and the steps that they can take to reduce the risk will have an immediate impact.

With the development of aquaculture in India during last decades, it was difficult to avoid introduction of alien species since they often command a higher market price than native fishes in international markets but rated low priced for domestic consumption (DeSilva*et al.*,2009). At present the aquaculturists prefer alien species because basic information and culture techniques are available for them and it is easy for them to adopt and compete in international market. Over the last two decades, the aquaculture entrepreneurs/ farmers have been demanding importation of many new fish strains and varieties for improved production and competition in the world market. However, environmental, socio-economic and biodiversity issues have been the important considerations for authorities. There is a National Committee for Introduction of Exotic Aquatic Species in Indian Waters under the Union Ministry of Agriculture, Department of Animal Husbandry, Dairying and Fisheries, New Delhi to check and regulate importation of alien fishes in India.

At the national level, quarantine and health certification programmes have been initiated as an integral part of much broader strategies aimed at protecting the natural environment and natural faunas from the deleterious impact of alien fish species and pathogens. A national Plan and Quarantine guidelines have been developed by NBFGR for execution by the aquaculturists and other stake holders culturing alien fishes in India. Fish Species specific guidelines have also been developed particularly for introduction of *O. niloticus, Pangasianodon hypophthalmus* and *Litopenaeus vannamei*and ornamental aquarium fishes. The quarantine facility required for alien fish species introduction has also been designed and can be adopted under public–private partnership mode. Considering the negative impacts of alien fishes on biodiversity, stringent regulations are imperative and all introductions are mandatory to pass through the National Committee on Introduction of Aquatic Species in Indian waters before import. The aquaculturists and farmers are advised to comply with the available regulatory mechanisms for all alien fish species along with strict conditions of sanitary and phyto-sanitary standards. Endeavour to limit introductions of alien species, and thus also their incidental negative impacts on native fish biodiversity, is inevitably connected with legislation which is lacking in India.

Potential risks related to intentional introductions of alien species can be reduced by careful consideration of an introduction before it occurs. A detailed protocols for this purpose has been developed by the NBFGR which can serve as guidelines for satisfactorily addressing environmental and biodiversity concerns. Possible measures for reducing the impact of inadvertent releases of exotic fish may be through early detection of escapes and prevention from spread. Any attempts to control or eliminate a problematic exotic species will require tremendous expense if actions are delayed until the exotic species firmly establishes. Prevention and public awareness should be the first approach and are understood to be a better option than measures of control or eradication. The education is not solely the responsibility of Public Administrations, either financially or otherwise rather aquaculturists should also behave responsibly and refrain from the illicit use of exotics. People in all walks of life must be made aware of the need for study and careful documentation of any unauthorized fish introduction and the potential for irreversible environmental impact of the illegally introduced fish even as single unwise action. To mitigate the

negative impacts of introduced fish species will require continued co-operation within governments, academia, and the private sector.

CONCLUSIONS

• Varying degrees of human interventions on fish introductions for aquaculture without adapting bio-security and bio-safety measures has been alarming.

• The established alien species have potential to disrupt the biological integrity of natural aquatic ecosystems.

• Alien species fundamentally have been found as indicators of loss of biological integrity and decline in river health.

ACKNOWLEDGEMENT

Author thankfully acknowledges the support and guidance of Dr. J.K. Jena, Director, NBFGR. The financial support of Uttar Pradesh State Biodiversity Board, Lucknow for conducting such study is also acknowledged.

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