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Review
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Exotic fish and decreasing habitats vis-à-vis conservation of freshwater fish biodiversity of Bangladesh

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Abstract
Multiple stressors including biological invasion have long been recognised in conservation of freshwater fish biodiversity. Works in this line have, however, been still scanty in Asia and South America – the continents known for rich biodiversity. In this study, the first of its type in Bangladesh, impacts of exotic fish and declining habitats on native fishes have been investigated. Regression and correlation analyses of 16 years production data of ponds, practically the only habitat where exotic fish are cultured commonly with indigenous ones, reveals that a maximum of 25% of the abundance decrease of native fish could be due to the effects of five commonly cultured exotic fish. Rest of the decline might largely be due to shrinkage, degradation, and destruction of habitats. Inland habitats other than ponds shrink, commonly, by about 80% during the dry season, and most rivers are heavily polluted except for the brief mid rainy season. Decline in native fish populations may result in reduced genetic diversity. Another potential danger is the probable genetic introgression from the less fit hatchery-originated fish with the wild ones. The study concludes that the native freshwater fishes are endangered by declining habitats, exotic fishes, genetic consequences of hatchery supplementation, etc.

Keywords: Aquaculture impacts; conservation; exotic fish; habitat shrinkage; native fish biodiversity

1 | INTRODUCTION

Worldwide, 480000 exotic (= non-native or alien) species have been introduced into various ecosystems (Pimentel *et al.* 2001), and as a consequence the biological invasion has become one of the key drivers for declining biodiversity (Caffrey *et al.* 2014; Veale *et al.* 2015). Though many introduced species do not deleteriously affect ecosystems (e.g., Gozlan 2008; Cucherousset and Olden 2011), overwhelming evidences indicate the profoundly negative effects of introductions on species and genetic diversity at both the local and global level (McNeely 2001; Bubb *et al.* 2009). However, not all exotic species establish after introduction. In fact, the 'tens rule' states that approximately ten per cent of all introduced species succeed in establishment, and about ten per cent of those established become pests (Williamson 1996).

Fishes are one of the major groups of introduced species, and a total of 624 fish species have been reportedly introduced worldwide (Gozlan 2008). Exotic fishes are considered one of the major causes of decrease of native fish diversity in freshwater ecosystems (Elvira and Almodovar 2001; Ribeiro *et al.* 2008). A survey of 31 fish introduction studies in Europe, North America, Australia, and New Zealand found that in 77% of the cases native fish populations were reduced or eliminated following the introduction of exotic fish species (Ross 1991).

Although occupy a small portion (<1%) of the aquatic world, freshwater habitats support ~10% of all known species including 33% of the vertebrates (Strayer and Dudgeon 2010). Unfortunately, freshwater is the most vulnerable among the ecosystems due to various reasons including over exploitation, water pollution, habitat degradation, flow modification and biological invasion (Dudgeon *et al.* 2006; Suski and Cooke 2007). It has been speculated that about 20% of the world's freshwater fish fauna is already extinct or is on the verge of extinction (Moyle and Leidy 1992).

Man is the main vector of freshwater fish movements across ecosystems or countries (Kennard *et al.* 2005; Dawson *et al.* 2017). Aquatic habitats in densely-populated countries are, therefore, more likely to be prone to biological invasion. Most studies on exotic aquatic species have been carried out in temperate regions, and a lack of knowledge exists in this regard in other regions including large part of Asia, Africa and South America (García-Berthou 2007; Dawson *et al.* 2017).

Bangladesh, a subtropical country with one of the highest population densities of the world, supports a large number of freshwater fish species (≥265 species) in its inland waters of 4.73 million ha (Rahman 2005; FRSS 2018). It is also one of the major fish producing countries in the world - 5th in aquaculture and 3rd in inland capture production (FAO 2018). The aquaculture production is almost entirely based on extensive or improved-extensive fish farming in ponds – a major habitat also for many indigenous fish species outside the culture scheme (Rahman 2005). However, the abundance and richness of freshwater fishes in Bangladesh are now at stake (Galib *et al.* 2018a, 2018b). The number of 'threatened or endangered/critically endangered' fishes has increased in recent times - 64 (IUCN Bangladesh 2015), compared to 54 (IUCN Bangladesh 2000). Moreover, 30 fish species are reported to have gone extinct from the rivers of the country (Hossain 2014). A range of factors including over-exploitation, water pollution and habitat degradation are regarded to be responsible for this decline (Hussain 2010). However, no studies have so far been carried out which could clearly identify the factors and their impacts on native fishes (c.f., Galib *et al.* 2018b). Despite the introduction of a large number of exotic fishes for aquaculture and ornamental purposes in Bangladesh since 1952 (Rahman 2005), and many reports of their intrusion into the wild (e.g., Galib *et al.* 2018a), the actual or potential impacts of the exotic species have not been evaluated so far. In this study, the impacts of exotic fishes on native taxa in pond ecosystems have been evaluated, and also the scenario of fish production, and degradation and habitat loss in inland open waters over time has been presented.

2 | METHODOLOGY

This review work investigates into two important aspects of the Bangladesh inland fisheries related to native fish conservation – (a) effects of the introduced exotic fish on the native ones, and (b) fish production and the habitat scenario, viz., shrinkage, degradation, destruction, etc., of the inland waters.

2.1 Impacts of exotic fishes on native species in pond ecosystem

Pond data have been used for the impact study. Though largely an artificial system, because of manipulations by culturists, pond production data are the only systematic type available in the country for this study.

Yearly production data from 2001-2002 to 2017-2018, excepting for the non-available 2011-2012 period, of pond fish species of the 64 districts of the country were collected from the annual reports of the Department of Fisheries (DoF), Bangladesh (FRSS 2002–2019). The ponds were of three kinds – culture, culturable (not yet under aquaculture, but suitable for it), and derelict. Traditionally, the last two are also suitable habitats for native fishes. The management process in culture ponds might negatively affect the natives; otherwise those are not inherently unsuitable for them. The analysis involved 15 species or major taxa – ten natives and five non-natives. The natives were *Labeo rohita*, *Labeo calbasu*, *Catla catla*, *Cirrhinus cirrhosus*, *Wallago attu*, Catfishes (*Clarias batrachus* plus *Heteropneustes fossilis*), Snakeheads (*Channa punctatus*, *Channa striatus*, *Channa marulius* and *Channa orientalis*), Minor Carps (*Labeo gonius* and *Labeo bata*), Others (*Puntius* spp., *Esomus* spp., *Salmostoma* spp., and other small indigenous species [SIS, species that grow <25 cm [Felts *et al.* 1996]), and Shrimps (*Macrobrachium* spp.), a common fisheries item of sizeable production that necessitated its inclusion in the analysis (regression and partial correlation). The exotic taxa included were *Hypophthalmichthys molitrix*, *Ctenopharyngodon idella*, *Cyprinus carpio*, Tilapia (*Oreochromis niloticus* and *Oreochromis mossambicus*), and *Barbonymus gonionotus*. These exotics, except for Tilapia, are principally Asian species, but have been introduced worldwide. In their natural ranges, they all occur in rivers, streams, lakes, reservoirs, ponds, inundated flood lands, etc. Among them, only *C. carpio* and Tilapia breed in ponds. Like these hatchery originated exotics, six of the natives (*L. rohita*, *L. calbasu*, *C. catla*, *C. cirrhosus*, *L. gonius* and *L. bata*) are now mostly hatchery-originated and stocked in ponds by fish farmers. The rest are naturally-grown self-recruiting species in pond ecosystem of the country. Comparison between groups can, therefore, reveal propagule pressure on self-recruiting native species.

Some more exotic fishes like the Milkfish (*Chanos*

chanos), African Catfish (*Clarias gariepinus*), Thai Pangas (*Pangasius hypophthalmus*), etc., were also introduced into the country for aquaculture. Of them, only the latter, introduced in 1990, has now become the most productive one in the Bangladesh culture fishery. All three have, however, been excluded from the impact study. The former two for poor production due to a lack of popularity, the latter for a different cause – an almost exclusively monoculture practice.

A data matrix of 15 taxa × 64 [districts] × 16 [years] was subjected to the multiple regression and partial correlation (Little and Hills 1978) analysis to evaluate the impacts of exotic species on native fishes (n = 1020 for each taxon [64×16 = 1024 - 4 irregularly missing data]). The partial correlation analysis is a better guide to impact study as it works in controlling the effects of the other co-occurring variables included in the analysis (Little and Hills 1978). All the analyses were carried out using the SPSS (version 19).

2.2 Non-native fishes in inland open waters of Bangladesh

A thorough literature review was undertaken to get the records of, or works there on, exotic fishes in the open waters of the country. Web of Science, Google Scholar, Research Gate databases, etc., were searched using "non-native / exotic / introduced / invasive fish of Bangladesh" as keywords. Personal profiles of researchers in university, research laboratory, etc., websites were also followed.

2.3 Production and habitat aspects of the inland open water fish

The major inland open water habitats are rivers, haors, beels, floodplains, the Kaptai Lake and the Sundarbans. The latter two have not been included in this study because of the substantial aquaculture practices in them, and also for the dearth of requisite data particularly from the ecotonic Sundarbans.

18 years of fish production data of rivers, haors, beels and floodplains were collected from DoF reports (FRSS 2002–2019). However, it was possible to collect area statistics for inland water habitats for a longer period (since 1983; FRSS 2001). Data on habitat shrinkage, degradation and destruction, the other important aspects of conservation of biodiversity, were collected from DBHWD (Department of Bangladesh Haor & Wetland Development), BIWTA (Bangladesh Water Transport Authority) and DoE (Department of Environment, Bangladesh) (DoE 2014–2019; DBHWD 2016). DoE publishes monthly water quality data of 28 important rivers of Bangladesh.

3| NATIVE AND EXOTIC FISHES IN PONDS

The persistent significant increase in the inland fish production over the last 50 years has been mostly due to the contribution of the exotic species. Pond area has largely (47%) increased, particularly over the last 18 years, from 0.266 to 0.392 million ha. This has been due to the tremendous increase of culture ponds (by 142%, from 0.159 to 0.392 million ha), with the concomitant decrease in culturable (0.069 million ha to nil) and derelict (0.038 million ha to nil) ponds during that period (Figure 1). Though native fish production has also increased, but the massive rise has been in the production of the exotic fish. For instance, while the contribution of the exotics was less than 50% of the total inland fish production in 2001–02, it has even massively surpassed the native fish production in 2017–18 (0.72 million metric tons [MT] for the natives, compared to 1.2 million MT for the exotic fish) (Figure 1). This tremendous increase of the exotics was bound to affect the native fish diversity in view of the usual limitation in space and resources.

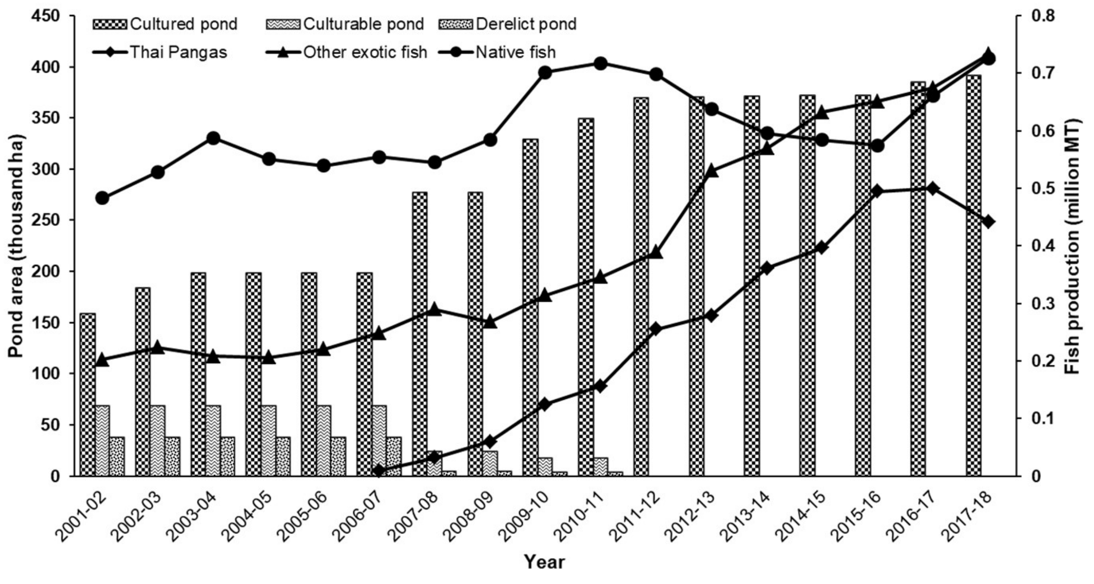

FIGURE 1 Areas of pond types and production of major kinds of pond fish.

The following account is based on the 2001 – 2018 production data of only pond fish, virtually the only sector where production increase has occurred. Major native fish like *L. rohita*, *C. catla*, C. cirrhosus and *L. calbasu*, Minor Carps, and Catfishes (*H. fossilis* and *C. batrachus*), all also increased between 2001 and 2018, though mostly at much lower rates than those of the exotics. The rates were 46, 25, 37, 35, 116% and 82%, respectively (Figure 2). Conversely, the smaller less available fishes, designated as Others in the impact analysis, decreased by ≤ 25% over that period. An exceptionally large increase (352%) has, however, occurred in the case of *Anabas testudineus*. But this has largely been due to the huge increase in the culture of the 'non-native gene pools of the same species – the Vietnamese and the Thai Koi', and for that *A. testudineus*, though a long cherished native of the country, has not been included in the impact investigation.

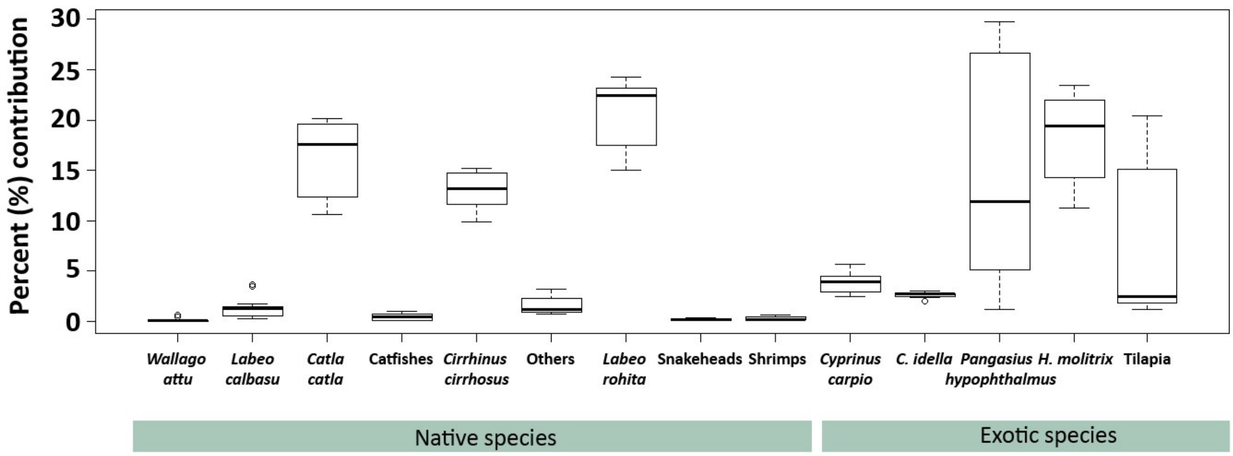

FIGURE 2 Boxplot showing mean percent contribution of various native and exotic fish species to the overall fish production in pond ecosystem in Bangladesh; based on data from 2001–02 to 2017–18 except for *Pangasius hypophthalmus* whose data were available since only 2007–2008. Midline within the box is the median; upper and lower limits of the box represent the third and the first quartile (75th and 25th percentile), respectively.

The increases of the majority exotic fishes, on the other hand, were rather astounding – Tilapia (1168%), *C. carpio* (234%), *B. gonionotus* (1390%), *P. hypophthalmus* (2971%) and *C. idella* (73%). The above mentioned data in parentheses are growth rates of the mean production data of the period 2002–03 to 2017–18 with respect to those of the values of 2001–02, except for the *P. hypophthalmus* whose production was only 9175 MT in 2006–07, when the data of this exotic catfish was made for the first time available to public by DoF, and which rose to a mean annual production of 259016 MT during the period 2006–07 to 2017–18. Among the exotic carps, *H. molitrix* was, however, the only one to decrease (–3%). Production increase of both native and exotic fishes was notably higher after 2011, than that of the previous period, and this was significantly much higher for the exotics ($p < 0.001$) than that for the natives ($p < 0.05$; Figure 3). This lesser abundance of the native fish may, reasonably, bring adverse genetic effect in them, as lower abundance can reduce adaptability and genetic fitness of a population.

Each of the exotic fishes had significant relationship with at least one native, except for *Wallago attu*, a predatory voracious fish (Figures 4 and 5). This was apparent from partial correlations, each controlling 13 variables (4 exotics and 9 natives). Seventy six percent of the significant effects were negative. *Hypophthalmichthys molitrix* and Tilapia were the most influential exotics, each affecting five native taxa. The former affected *L. calbasu*, Shrimps, Catfishes, Others, and Minor Carps. Tilapia affected *L. rohita*, *C. catla*, *L. calbasu*, *C. cirrhosus*, and Others. *Ctenopharyngodon idella*, *C. carpio* and *B. gonionotus* each affected only one native fish - the former *L. rohita*, and both the latter two only *C. catla*. Four of the significant correlations were, unusually, positive - *H. molitrix* with *C. cirrhosus*, *C. carpio* with Shrimps, Tilapia with Catfishes, and *B. gonionotus* with Snakeheads.

Of the 13 significant negative relationships among the exotic and the native fishes (Figure 4), only seven can be, at least to some extent, due to competitive or overlapping food habit. These are between *H. molitrix* (principally phytoplanktivorous, secondarily zooplankton feeder [Rahman 2005]) and *L. calbasu* (herbivore, feeds algae, vegetable debris, decaying organic matter, and also molluscs [Imran *et al.* 2014; Gupta and Banerjee 2015]); between *H. molitrix* and Minor Carps (mainly algae and vegetation feeder [Shafi and Quddus 2001; Joadder 2014]); between *C. idella* (voracious herbivore consuming higher aquatic plants, also detritus, insects and other invertebrates [Chilton and Muoneke 1992; Jones *et al.* 2017]) and *L. rohita* (principally phytoplanktivorous, also feeds on decaying higher plants and detritus [Bakhtiyar *et al.*

2017; Khaing *et al.* 2019]); between Tilapia (omnivorous, mainly phytoplanktivorous herbivore, also feeds zooplankton, worms, detritus [Tesfahun and Temesgen 2018; Hatta *et al.* 2019]) and each of *L. rohita*, *C. catla* (planktivorous, preferring zooplankton than phytoplankton [Ahmed *et al.* 2000; Kumar *et al.* 2007]), *L. calbasu*, and *C. cirrhosus* (herbivorous, essentially a plankton feeder [Latifa 2007]).

The other six significant negative correlations that could not be due to feeding competition were between *H. molitrix* and Shrimps (carnivorous, feeds small crustaceans, aquatic insects, diatoms, also organic matter [Paul 2005]); between *H. molitrix* and Catfishes (predaceous carnivore, bottom feeder taking crustaceans, even small fish, detritus [Narejo *et al.* 2016; Khaing *et al.* 2019]); between *H. molitrix* and Others (an assemblage of SIS, of which the majority species are predaceous and carni-omnivorous, and only few consume plant materials [Shafi and Quddus 2001; Gupta and Gupta 2006]); between *C. carpio* (benthic omnivore feeding chrionomids, cladocerans, ostracods, annelids, molluscs, even plant materials [Laird and Page 1996; Hatta *et al.* 2019]) and *C. catla*; between Tilapia and Others, and between *B. gonionotus* (herbivorous, also feeds insects [de Silva and Kortmulder 1976; Siaw-Yang 1988]) and *C. catla*. Other than the complex ecological consequences because of the new inhabitants' (the exotics) 'human-assisted-exploitation' of the natives' resources and niches, nothing can be assumed presently.

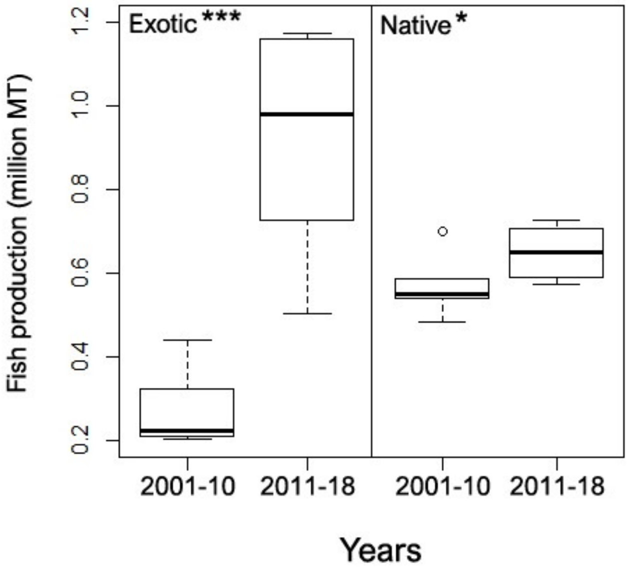

FIGURE 3 Boxplot showing the native and the exotic fish production over time. Midline within the box is the median; upper and lower limits of the box represent the third and the first quartile (75th and 25th percentile), respectively. Production of both groups differed significantly (Mann–Whitney *U* test: *Native fishes, $U = 62$, $p = 0.011$; ***Exotic fishes, $U = 72$, $p < 0.001$).

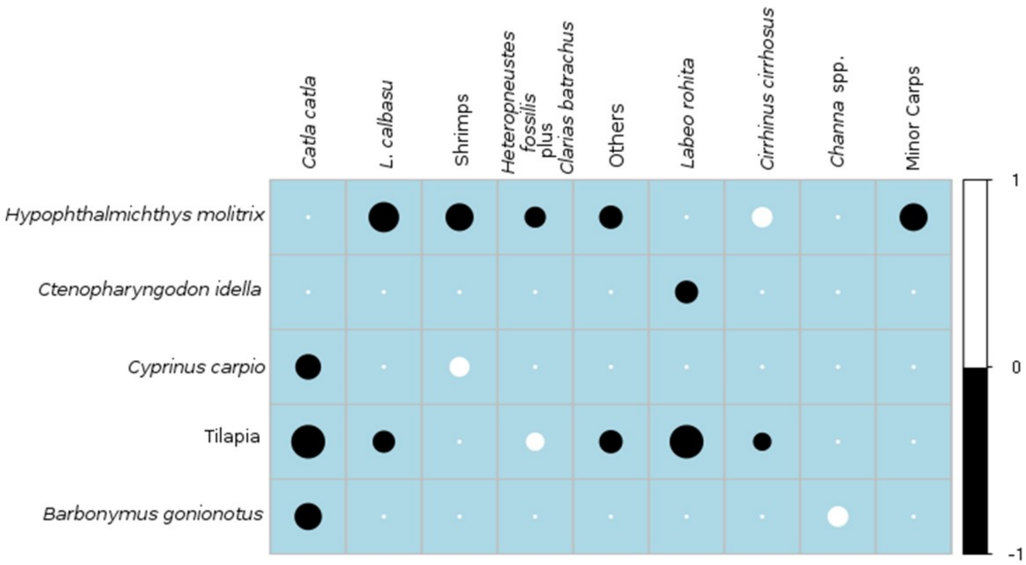

FIGURE 4 Partial correlations plot among the exotic and the native fishes.

Four of the significant relationships between the exotic and the native fishes were, rather unusually, positive. They were between *H. molitrix* and *C. cirrhosus*; *C. carpio* and Shrimps; Tilapia and Catfishes, and between *B. gonionotus* and Snakeheads. Though, a number of works have reported positive relationships between non-fish exotics and natives (Sagoff 2005; Goodenough 2010), definite report of that sort of relationship between exotic and native fish is not known. However, in an earlier work done in Bangladesh, Habib *et al.* (2003) found a positive relationship between *H. molitrix* and *C. cirrhosus*, which the authors attributed to the bottom digging and probing habit of *C. cirrhosus* that releases nutrient materials from substratum facilitating production of phytoplankton, the principal food of *H. molitrix*. On the other hand, Amir *et al.* (2013) reported a contrary negative relationship between *H. molitrix* and *C. cirrhosus* from Pakistan.

The presently observed positive relationship between *B. gonionotus* and Snakeheads could be the result of interactions involving a third fish (Tilapia). *Barbonymus gonionotus* and Tilapia compete for food (Haroon 1998), whereas Snakehead plays an effective role in controlling the overpopulation of Tilapia (Yi *et al.* 2004), which can indirectly facilitate *B. gonionotus*. For instance, Dill *et al.* (2003) and Schmitt (1987) observed that indirect effects (i.e., trophic cascade) occur in multispecies assemblages when the action of one species causes a change in a second species, subsequently impacting on a third species.

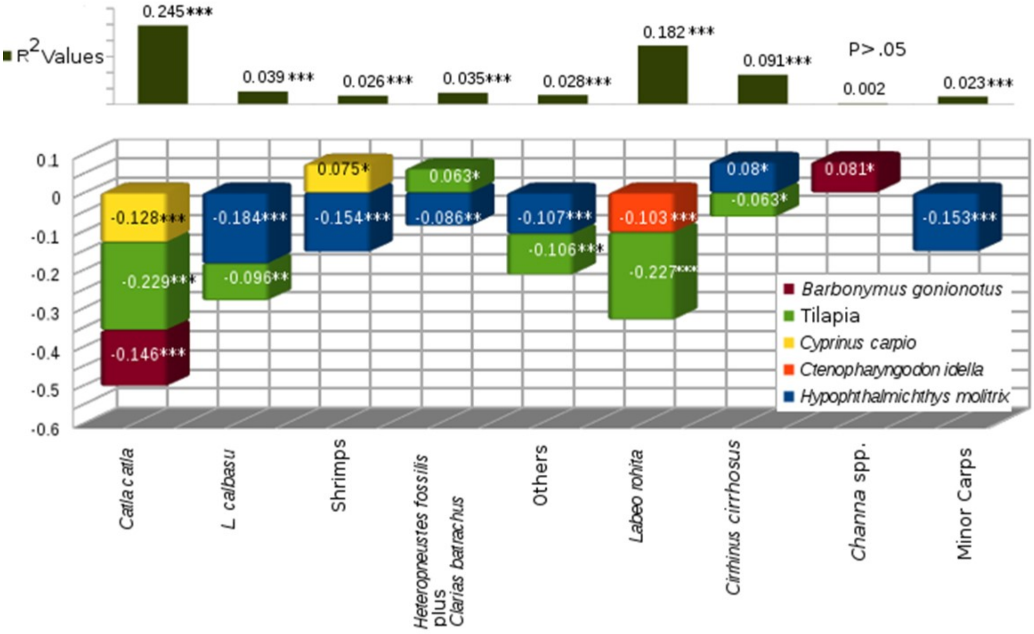

FIGURE 5 Multiple and individual effects of the exotic fishes on the natives.

The pond breeding nature of *C. carpio* and Tilapia might, however, indicate a clue to a sort of positive relationship or proto-cooperation between them and native fish. Those exotics, especially the later one, have prolific new generation building capacity (Galib and Mohsin 2011; Imteazzaman and Galib 2013). The fries and young in ponds of these fishes may help as food sources to some (Catfishes, shrimps, etc.) of the native fish species or taxa, which do include fish fries and young in their food menu. The powerful generation increasing capacity of those two exotic species is also thought to be partly responsible for the disappearance, or at least much reduced abundance, of the SIS (about 25 small pond fish species) from the obvious effect of decreasing resources due to competition (Ameen 1987).This situation of the SIS can logically open up new resources for other native fishes. This proto-cooperation is not uncommon in nature (Carlander 1955; Geist 2010). It is known that the functioning of an ecosystem is a very complex process where complicated food web and interactions do run – a break in one thread of the net can affect the functioning of one or few of them, which can affect the overall functioning of the ecological unit called ecosystem (Bøhn 2007).

Despite some arguably positive effects on biodiversity by introduced species, or observation like 'most introduced species do not deleteriously affect ecosystems' (Gozlan 2008; Cucherousset and Olden 2011), overwhelming evidence indicates the profoundly negative effects of introductions on native biodiversity. Regarding the effect of an exotic on a native species, the conclusion from a prolong work (Bøhn 2007) on the invasion by Vendace (*Coregonus albula*) of Lake Inari, Northern Finland, is pertinent here. In that invasion, 90% reduction of the native zooplanktivorous white fish (*Coregonus lavaretus*) resulted from the wiping out, by Vendace, of four large zooplankton species, the food of the white fish. Bøhn concluded that "only the direct effect might be marked; the indirect ones are harder to follow, and no researchers at all would pretend to fully understand which mechanisms were responsible for the effects shown, even though the scientific discipline of invasion biology has 50–100 years of active research to acknowledge".

4 | EXOTIC FISHES IN INLAND OPEN WATERS

Twelve exotic fish species have been reported from the inland open waters of Bangladesh by 51 studies, conducted between 1999 and 2020 (Table 1). Prior to this period no study reported any occurrence of exotic fish in the country's natural waters. Six studies, published between 1999 and 2005, reported the existence of 6 exotic fish species in 3 beels, 1 lake (two studies on Kaptai Lake, part of a river system) and 1 baor. Eleven, published between 2005 and 2010, recorded 9 exotic fish, followed by 22 works between 2010 and 2015, and 12 between 2015 and 2020, recording 9 and 11 exotic fish, respectively. This evidently shows an increasing invasion trend by the exotic fish of the open waters of Bangladesh.

Chinese carps were commonly reported than other exotics, but tilapias were also a common invader. Silver carp was the most commonly found species in all types of inland open water (Table 1). However, more recently, since 2010, the suckermouth catfish (*Pterygoplichthys* *pardalis*) has also been recorded from different rivers of the country (Chaki *et al.* 2014, Galib 2015).

TABLE 1 Occurrence of exotic fish species in natural waters of Bangladesh.

Exotic fish	Occurrence in habitats (%) during 1999 - 2020				
	River (*n*=22)	Beel (*n*=19)	Haor (*n*=7)	Baor (*n*=2)	Lake (*n*=2)
Hypophthalmichthys molitrix	86.4	78.9	85.7	100	100
Hypophthalmichthys nobilis	40.9	42.5	0	50	0
Ctenopharyngodon idella	36.4	78.9	71.4	100	100
Cyprinus carpio	45.5	78.9	85.7	100	100
Barbonymus gonionotus	18.2	68.4	28.6	0	100
Oreochromis niloticus	22.7	42.1	28.6	0	100
Oreochromis mossambicus	31.8	42.1	71.4	50	0
Clarias gariepinus	4.5	0	0	0	100
Pterygoplichthys pardalis	13.6	0	0	0	0
Pygocentrus nattereri	0	0	14.3	0	0

5 | INLAND OPEN WATERS: FISH PRODUCTION AND HABITATS

The open water fish production had been virtually stagnant during 1983 – 2004, excepting for a minor growth during the preceding 14 years (1991–2004) (Figure 6). The moderate increase observed thereafter (2005–2018) was, probably, the result of some pragmatic steps like banning of fishing in the breeding season of major fish species, the establishment of some 500 sanctuaries (FRSS 2018), hatchery supplementation, etc. However, the common impression is that the availability of fish in the open waters has been visibly decreasing due to shrinkage, degradation and destruction of habitats.

5.1 Rivers

Rivers are the most important wetland of Bangladesh. No definite data are yet to be available regarding the total areas of those rivers for the maximum and the minimum inundations. However, FRSS (2016) recorded the area of 'Rivers and Estuaries' as only 853863 ha, whereas a contemporary study in 2015 by CEGIS (Center for Environment and Geographical Information Service) for the Department of Forest and Environment of Bangladesh, reported the total area of 'Rivers and Khals' as 1265743 ha (from CEGIS database). 'Khals' (canals), and distributaries and tributaries of most rivers dry up during the dry season, November to May (Haque 2018).

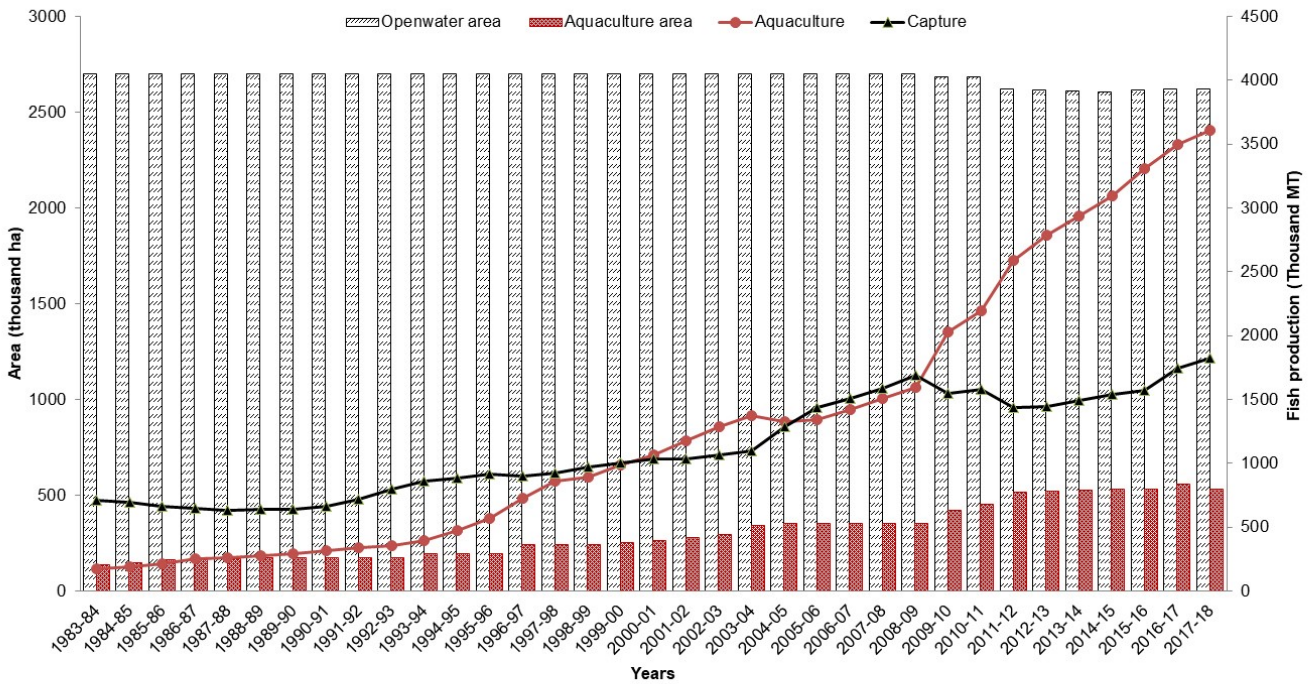

FIGURE 6 Inland water areas and fish production of Bangladesh over time.

Using morphometric data of DBHWD (2016), we have calculated the total area of rivers of Bangladesh as 1077491 ha (perennial, 1002961 ha; seasonal, 74530 ha), and that has been used here. River areas have, however, considerably shrunk over the last 40 years. Large reduction in the quantum and flow of water, mainly due to upstream diversion beyond the country's boundary, in the Ganga-Padma, the Bhrahmaputra-Jamuna, and the Meghna river systems, the three biggest river systems of Asia, evidently expresses that shrinkage. The substantial reduction of the country's inland naval route is also a testimony to that. Compiling data and reports of a number of surveys undertaken by the BIWTA (Bangladesh Inland Water Transport Authority), Mishra and Hussain (2012) reported that 12000 km of waterways were navigable during the 1960s, which continued up to the early 1970s; in the following 15 years navigability of the rivers deteriorated such that 50% of the IWT routes were closed. Presently, the total length of navigable waterways during the monsoon will not exceed 4000 – 4500 km, of which only 2000 – 2500 km are navigable during the low water period (BIWTA records).

Habitat degradation, besides shrinkage, is a significant factor in the conservation of biodiversity (Dudgeon *et al.* 2006; Suski and Cooke 2007). Most of the rivers adjacent to the industrial places of the country have become polluted. Majority of the 28 rivers, whose water qualities are recorded monthly by the DoE, Bangladesh, have different grades of pollution, and virtually devoid of fish except for the rainy season. Their total area is no less than 37261 ha. Besides this, it is generally regarded that at least 50 – 60% of these rivers' area shrinks during the lean period. Anoxia situation was recorded in three rivers (Bali, Buriganga and Turag; Figure 7) with many heavy industries along their banks.

Nearly two hundred (197) freshwater fish species, including 106 exclusive ones, inhabit the rivers of Bangladesh (Rahman 2005). Riverine fisheries of the country has long been under serious pressure from manifold causes, the principal ones are large scale urban and industrial abuses of rivers, ever increasing abstraction of surface and underground waters, competition from exotic fish, pollution, climate change, etc. Fishermen have long been reporting lower catches in most of the rivers, but much of the evidence is anecdotal or circumstantial (Tsai and Ali 1995). The authors, however, observed that this decline has persisted for more than forty years (Tsai and Ali 1995). Similarly, DoF (1983–1991) reported that total riverine fisheries production declined by 44% - 207000 t in 1983 to only 124000 t in 1991.

5.2 Floodplains

Floodplain is a low lying area, flooded by overspill from adjacent rivers, beels, haors, and by congested rain waters (Agüero 1989; Rahman and Akhter 2015). Bangladesh has one of the most extensive floodplains in the world (Jhingran 1997). They are spread over 9.3 million ha including 2.83 million ha of paddy fields (Welcomme 1979) that go under 2 to 6 m deep water for 3 to 4 months every year. However, DoF, Bangladesh, has recorded the area as only 2832792 ha in 2009, that too reduced to 2712618 ha by 2017. This wetland comprises ~70% of the open water (capture fishery) area and production (FRSS 2007–2018). It is rich in nutrients and fish food, and is the feeding and grazing ground of almost all inland fishes (Rahman and Akhter 2015).

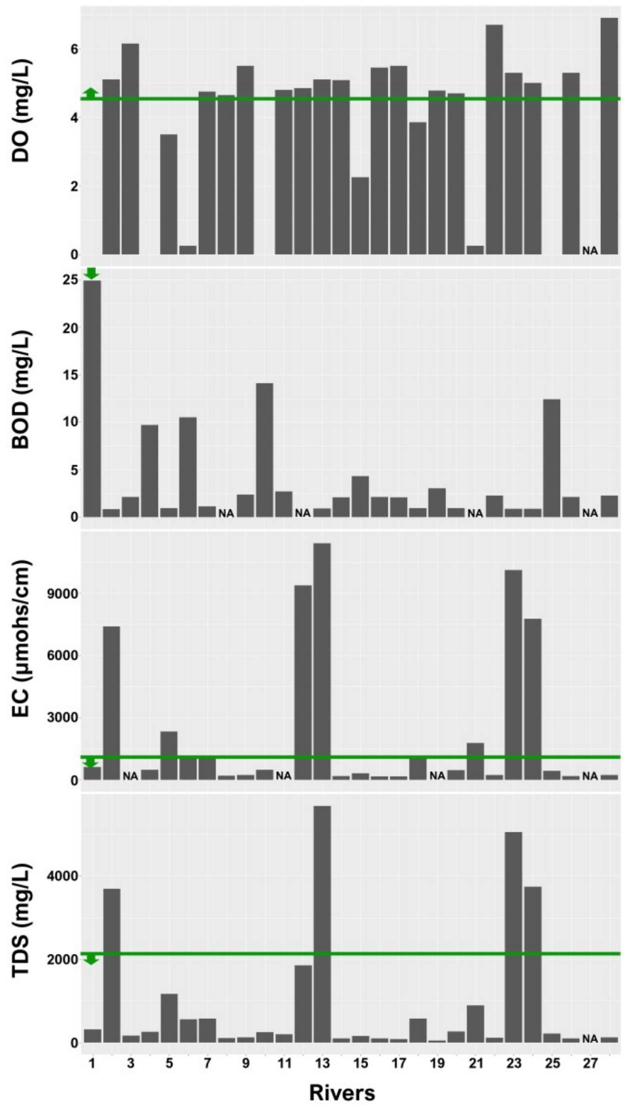

FIGURE 7 Important water quality parameters (during 2017 & 2018; minimum for DO, mean for others) in major rivers of Bangladesh (1, Bali; 2, Bhairab; 3, Brahmaputra; 4, Buriganga; 5, Dakatia; 6, Dhaleshwari; 7, Gorai; 8, Halda; 9, Jamuna; 10, Turag; 11, Kaliganga; 12, Karnaphuli; 13, Khaksiali; 14, Kirtankhola; 15, Korotoa; 16, Tetulia; 17, Lohalia; 18, Mathavanga; 19, Meghna; 20, Modhumoti; 21, Mayuri; 22, Padma; 23, Pashur; 24, Rupsha; 25, Shitalakhya; 26, Sughanda; 27, Surma; 28, Teesta). Green bars and arrows represent desirable limit and direction of the parameters for the habitats. Missing data were represented by NA

The rate of fish yield from floodplains ranges between 85 and 205 kg ha^{-1} yr^{-1} with an average of 142 kg ha^{-1} yr^{-1} (Rahman 1989). This habitat has, however, long been shrinking, degrading, etc., from manifold causes, all basically connected with an ever-increasing human population and their basic needs of housing, communication, protection from calamities like flood, etc. Extensive roads, flood-control dams, etc., have been built affecting over all the flood regime, the fundamental determinant of the floodplain ecosystem.

Sixty per cent of the freshwater fish species in Bangladesh are floodplain dependent (Boyce 1990). One hundred and forty three of them belong to the category of 'small fish' (≤250 mm) (Felts *et al.* 1996), and are important members of the floodplain fisheries, constituting 40% of the inland fish catch (Minkin *et al.* 1997). Species diversity and production of these fishes have, however, declined due to many anthropogenic activities and disturbances. At least 32 fish species have declined for those causes (Rahman and Akhter 2015).

Fish production from floodplains decreased from 84 kg ha^{-1} yr^{-1} in 1970–1980 to 65 kg ha^{-1} yr^{-1} in 1986–1987 (Hossain and Afroze 1991). Then an increasing trend was observed from 1990 to 2000. However, that increasing trend does not necessarily mean an inherent increase in diversity and production. It could have been due to the stocking programme implemented by DoF through Community Based Fisheries Management (CBFM) projects (Rahman and Akhter 2015). Increase of fishing pressure by an increasing human population can also be a very probable cause.

5.3 Haors

Haors are in fact seasonal freshwater lakes forming a special type of inland wetland. They are an integral part of the floodplains of Bangladesh. There are 373 haors in the country, spreading over 858460 ha (DBHWD 2016). Among the larger ones, the Hakaluki (21500 ha) and the Tanguar (11700 ha) are quite gigantic. Normally, haors are full of water at the end of the monsoons, generally during August – September. Thereafter water starts receding and mostly dries up during the winter and the summer leaving some deep pockets (beels), which act as fish sanctuary and mother fishery. There are some 6300 beels in the haor basin, out of which about 3500 are permanent and 2800 seasonal. Most of the haor waters shrink, even by about 90 – 100%, during the dry season (Salauddin and Uddin 2011; Nahar *et al.* 2018).

Haor fish have been seriously endangered from habitat modification, degradation, destruction, indiscriminate fishing, overfishing, etc. Flood control steps, new agricultural technologies and construction of road networks in the haor area during the last 50 years since 1960 have altered the ecology of haors (Ali 1991; Khan 1993). Consequently, fish diversity, density and production from haors have declined drastically. The major carps virtually disappeared from the haors of Sylhet division as a result of irrigation and embankment projects (Rahman and Akhter 2015). The major carp catch from the haors of Sunamganj declined from 66.4% in 1967 to only 1.3% in 1984 (Tsai and Ali 1985).

5.4 Beels

Beel is a local name for a lake-like wetland with static water in the flood plains of Bangladesh (DoF 2007). They are usually formed by silt deposition, during flood spills, on the banks of big rivers creating discontinuous raised lands with big depressions in between. Shifting of the course of rivers and land subsidence also create beels. Beels are spread all over the country, except for the Hill Tracts of the southeastern region. Normally they remain deeply flooded for most of the wet season, and their rims are commonly used for rice cultivation. Beels are valuable fish and wildlife habitats (Galib *et al.* 2018a).

The canals linking beels and rivers enable riverine fishes, particularly the major carps, and also catfish and clupeids, to migrate to their spawning grounds in beels. These grounds have, however, been greatly lost or shrunk or deteriorated by habitat alterations, mainly by Flood Control Drainage (FCD)/Flood Control Drainage and Irrigation (FCDI) structures, road communications, housing, cultivation, etc., resulting in massive decrease in fish production from this type of inland water.

Total beel area amounts to about 81759 ha (DBHWD 2016), which however is increasingly getting shrunk due to many natural and anthropogenic causes. For instance, Islam and Kitazawa (2013) reported that the area of the Chalan Beel, the largest one among the beels, was 2635 km^2 in the wet season of 1967 which got reduced to 769 km^2 in the same period of 2010, and the dry season area in 2012 was 73 km^2 only. This beel is now, however, regarded by some researchers (e.g., Galib *et al.* 2009a, 2009b; Samad *et al.* 2009) as to have become a typical floodplain, mainly because of its loss of depth, general contour, and a low plain land like appearance for most of the year.

Fish yield in beels declined from 450 kg ha^{-1} in 1983–1984 to 247 kg ha^{-1} in 1989–1990, a decline of 45% (Ali 1997). It is well recognized now that fish production declined in beels all over the country (Rahman and Akhter 2015).

6 | CONCLUSIONS

Analysis of the pond fish production data of the last 16 years, up to 2018, reveals that a maximum of 25% of the abundance decrease of native fish could be due to the effects of the five exotic fish, viz., *H. molitrix*, *C. idella*, *C. carpio*, Tilapia, and *B. gonionotus*. The rest of the decline might largely be due to habitat shrinkage, degradation, and destruction. Consequent with the more than 200% increase of human population over the last 50 years, and meeting up of their basic needs like development of communication, housing, etc., 'that habitat loss' had been inevitable. Though the DoF data indicate recent increase of open water fish production, the general impression is that native fish of open water are increasingly getting diminished. Just to face the increasing fish demands of a big population, the onus has been shifted to culture fishery over the last 30 years. This fishery is mostly based on induced breeding and hatchery supplementation, followed by monoculture, or selected polyculture of exotic fish in ponds, commonly along with the major native carps.

So far there is no published report in Bangladesh on the genetic effect, like hybridization, of exotic on native fish. However, the effects of exotic species commonly occur in indirect way like decrease of native population through competition for limited space and resources that causes inbreeding depression. Another important factor in the conservation of native fish diversity is the effect of hatchery supplementation. Hatchery fish have lower fitness in natural environments than wild fish, and this fitness decline can occur very quickly, sometimes following one or two generations of captive rearing (Araki *et al.* 2008). In many cases a negative effect occurs on the diversity and variation of the wild population through introgression of genetic change acquired by breeding with hatchery developed progenies (e.g., Araki and Schmid 2010), which have low reproductive success in the wild, often only ≈ 10% of that of the wild fish (e.g., Berejikian and Ford 2004). Induced-breeding-based hatchery supplementation to aquaculture has long, no less than 40 years, been practiced in Bangladesh. In almost all cases this is done using adults from subsequent hatchery-raised-generations. This practice has become the main contributor to the huge increase of production in the culture fishery sector. As the open water fish production has not much scope of increase due to habitat shrinkage, degradation, etc., the country's fish production will continue to depend on pond culture, along with the apprehended genetic change.

Twelve exotic fish have already been reported from the country's open waters. It is not known whether any one has established breeding population in the wild, though five of them, the specially treated ones here, have already established, on introduction, breeding populations in both tropical and temperate countries (Welcomme 1988; van der Lee *et al.* 2017; Froese and Pauly 2019). It is generally regarded that a harmful consequence of introduction is the increasing homogenization of the distribution of species on Earth (Lövei 1997), though at the expense of indigenous species, at least partly, with the consequent reduction in global species diversity (McNeely 2001).

More than 500 sanctuaries (DoF 2017) have been established since 1960 (Hossain 2014), for which it is claimed that not only the rarely available fish like *Batasio batasio*, *Batasio tengana*, *Dermogenys pusillus*, *Gagata youssoufi*, *Plotosus canius*, *Danio rerio*, *Puntius terio*, *Nandus nandus*, *Apocryptes bato*, *Colisa chuna*, *Tetraodon cutcutia*, *Channa orientalis*, *Botia dario*, etc., are reappearing, the open water fish production has also been increasing. IUCN Bangladesh (2015) observed that not only any extinction of inland fish has occurred so far, the number of the Critically Endangered species has come down as well - 12 in IUCN Bangladesh (2000) and 9 in IUCN Bangladesh (2015). On the whole, it is considered that the open water fish diversity of Bangladesh has not undergone any significant change over the last 50 years, though the common feeling is that a good number of species of small fish are about to be lost, if not already so.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTION

MAGK designed and coordinated the study. All except **RK** worked in collection, processing and analysis of data. **SMG** and **RK** did the data visualisation part. **MAGK**, **SMG** and **MH** prepared the manuscript. All authors gave final approval for publication and agree to be held accountable for the work performed therein.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

REFERENCES

Agüero M (1989) Inland water fisheries of Bangladesh: management options and national interventions. In: Agüero M, Huq S, Rahman AKA, Ahmed M (Eds) Inland fisheries management in Bangladesh. Department of Fisheries, Dhaka, Bangladesh; Bangladesh Centre for Advanced Studies, Dhaka, Bangladesh, and International Centre for Living Aquatic Resources Management, Manila, Philippines. 149 pp.

Ahmed ZF, Wahab MA, Haq MS, Miah MAH (2000) Evaluation of food selection of *Catla catla* (Hamilton) fingerling by determining electivity index grown in earthen ponds in Bangladesh. Pakistan Journal of Biological Sciences 3: 1066–1068.

Ali MY (1991) Towards sustainable development: fisheries resource of Bangladesh. Ministry of Environment and Forest and National Conservation Strategy Sect, Bangladesh Agriculture Research Council, Dhaka. 56 pp.

Ali MY (1997) Fish, water and people, reflections on inland open water fisheries resources in Bangladesh. The University Press Limited, Dhaka, Bangladesh.

Ameen M (1987) Fisheries resources and opportunities in freshwater fish culture in Bangladesh. DANIDA Project Report, NRD-II Project, Noakhali, Bangladesh.

Amir I, Afzal M, Tahir H, Asmara I, Naz S, Fakhra S (2013) Effect of varying species ratios of silver carp (*Hy-*

pophathalmicthys molitrix) and mrigal (*Cirrhinus mrigala*) at constant density on pond fisheries in composite fish culture. ARPN Journal of Agricultural and Biological Science 8: 616–620.

Araki H, Berejikian BA, Ford MJ, Blouin MS (2008) Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications 1(2): 342–355.

Araki H, Schmid C (2010) Is hatchery stocking a help or harm? Aquaculture 308: S2–S11.

Bakhtiyar Y, Langer S, Karlopia SK, Chalotra RK (2017) Studies on the feeding habits of *Labeo rohita* (Ham.) from Gho-Manhasa fish ponds, Jammu, North India. Journal of Ecophysiology and Occupational Health 17: 40–49.

Berejikian BA, Ford M (2004) A review of relative fitness of hatchery and natural salmon. Northwest Fisheries Science Center, Seattle, USA.

Bøhn T (2007) Invasion of exotic species: lessons for GMOs? In: Traavik T, Lim LC (Eds) Biosafety first - holistic approaches to risk and uncertainty in genetic engineering and genetically modified organisms. Third World Network and GenØk.

Boyce JK (1990) Birth of a mega project: political economy of flood control in Bangladesh. Environmental Management 14(4): 414–428.

Bubb DH, O'Malley OJ, Gooderham AC, Lucas MC (2009) Relative impacts of native and non-native crayfish on shelter use by an indigenous benthic fish. Aquatic Conservation: Marine and Freshwater Ecosystems 19: 448–455.

Caffrey J, Baars J-R., Barbour J, Boets P, Boon P, ... Lucy F (2014) Tackling invasive alien species in Europe: the top 20 issues. Management of Biological Invasions 5(1): 1–20.

Carlander KD (1955) The standing crop of fish in lakes. Journal of the Fisheries Research Board of Canada 12: 543–570.

Chaki N, Jahan S, Fahad MFH, Galib SM, Mohsin ABM (2014) Environment and fish fauna of the Atrai River: global and local conservation perspective. Journal of Fisheries 2(3): 163–172.

Chilton EW, Muoneke MI (1992) Biology and management of grass carp (*Ctenopharyngodon idella*, Cyprinidae) for vegetation control: a North American perspective. Reviews in Fish Biology and Fisheries 2: 283–320.

Cucherousset J, Olden JD (2011) Ecological impacts of nonnative freshwater fishes. Fisheries 36: 215–230.

Dawson W, Moser D, van Kleunen M, Kreft H, Pergl J, ... Essl F (2017) Global hotspots and correlates of alien species richness across taxonomic groups. Nature Ecology & Evolution 1: 0186.

DBHWD (2016) Classifications of wetlands of Bangladesh, Volume 1–5. Department of Bangladesh Haor and Wetland Development, Ministry of Water Resources, Dhaka, Bangladesh.

de Silva SS, Kortmulder K (1976) Some aspects of the biology of three species of *Puntius* (= *Barbus*) (Pisces, Cyprinidae), endemic to Sri Lanka. Netherlands Journal of Zoology 27: 182–194.

Dill LM, Heithaus MR, Walters CJ (2003) Behaviorally mediated indirect interactions in marine communities and their conservation implications. Ecology 84: 1151–1157.

DoE (2014–2019) River water quality report 2013-2018. Department of Environment, Ministry of Environment and Forests, Dhaka, Bangladesh.

DoF (1983–2017) National fish week compendium. Department of Fisheries, Ministry of Fisheries and Livestock, Dhaka, Bangladesh.

Dudgeon D, Arthington AH, Gessner MO, Kawabata Z-II, Knowler DJ, ... Sullivan CA (2006) Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81: 163–182.

Elvira B, Almodovar A (2001) Freshwater fish introductions in Spain: facts and figures at the beginning of the 21st century. Journal of Fish Biology 59: 323–331.

FAO (2018) The state of world fisheries and aquaculture 2018 - meeting the sustainable development goals. Food and Agriculture Organization of the United Nations, Rome.

Felts RA, Fajts F, Akteruzzaman M (1996) Small indigenous fish species culture in Bangladesh (technical brief). IFADEP Sub Project 2. Development of Inland Fisheries, Dhaka, Bangladesh.

Froese R, Pauly D (2019) FishBase. World Wide Web electronic publication. www.fishbase.org, version (12/2019).

FRSS (2001–2019) Yearbook of fisheries statistics of Bangladesh 2017-18. Fisheries Resources Survey System, Department of Fisheries, Ministry of Fisheries and Livestock, Dhaka, Bangladesh.

Galib SM (2015) Fish fauna of the Brahmaputra River, Bangladesh: richness, threats and conservation needs. Journal of Fisheries 3(3): 285–292.

Galib SM, Lucas MC, Chaki N, Fahad FH, Mohsin ABM (2018a) Is current floodplain management a cause for concern for fish and bird conservation in Bangladesh's largest wetland? Aquatic Conservation: Marine and Freshwater Ecosystems 28(1): 98–114.

Galib SM, Mohsin ABM (2011) Cultured and ornamental exotic fishes of Bangladesh: past and present. LAP LAMBERT Academic Publishing, Germany.

Galib SM, Mohsin ABM, Parvez MT, Lucas MC, Chaki N, ... Islam MN (2018b) Municipal wastewater can result in a dramatic decline in freshwater fishes: a lesson from a developing country. Knowledge and Management of Aquatic Ecosystems 419: 37.

Galib SM, Samad MA, Kamal MM, Haque MA, Hasan MM

(2009a) A study on fishing gears and methods in the Chalan Beel of north-west Bangladesh. Journal of Environmental Science & Natural Resources 2: 213–218.

Galib SM, Samad MA, Mohsin ABM, Flowra FA, Alam MT (2009b) Present status of fishes in the Chalan Beel-the largest Beel (wetland) of Bangladesh. International Journal of Animal and Fisheries Science 2: 214–218.

García-Berthou E (2007) The characteristics of invasive fishes: what has been learned so far? Journal of Fish Biology 71: 33–55.

Geist J (2010) Strategies for the conservation of endangered freshwater pearl mussels (*Margaritifera margaritifera* L.): a synthesis of conservation genetics and ecology. Hydrobiologia 644: 69–88.

Goodenough AE (2010) Are the ecological impacts of alien species misrepresented? A review of the "native good, alien bad" philosophy. Community Ecology 11: 13–21.

Gozlan RE (2008) Introduction of non-native freshwater fish: is it all bad? Fish and Fisheries 9: 106–115.

Gupta S, Banerjee S (2015) A review on *Labeo calbasu* (Hamilton) with an emphasis on its conservation. Journal of Fisheries 3(3): 301–308.

Gupta SK, Gupta PC (2006) General and applied ichthyology (fish and fisheries). S. Chand and Co. Ltd., Ram Nagar, New Dehli, India.

Habib MAB, Sarker B, Hossain MS, Sarder MRI (2003) Species interaction between carp species in polyculture system. Bangladesh Journal of Fisheries Research 7(1): 27–32.

Haque MI (2018) Water resources management in Bangladesh. Anushilan, Chuadanga and Dhaka, Bangladesh.

Haroon AKY (1998) Diet and feeding ecology of two sizes of *Barbodes gonionotus* (=*Puntius gonionotus*) and *Oreochromis* sp. in ricefields in Bangladesh. Naga, ICLARM Quarterly 21(3): 13–19.

Hatta M, Umar NA, Mulyani S, Suryani I (2019) Study food habits of fishes in Tempe Lake. International Journal of Environment Agriculture and Biotechnology 4: 1217–1222.

Hossain MA, Afroze S (1991) Small fishes as a resource in rural Bangladesh. Fishbyte 9: 16–18.

Hossain MAR (2014) Habitat and fish diversity: Bangladesh perspective. Recent Advances in Fisheries of Bangladesh. Proceedings of 5th Fisheries Conference and Research Fair 2012. Bangladesh Agricultural Research Council and Bangladesh Fisheries Research Forum, Dhaka, Bangladesh.

Hussain MG (2010) Freshwater fishes of Bangladesh: fisheries, biodiversity and habitat. Aquatic Ecosystem Health & Management 13: 85–93.

Imran S, Nagar S, Jha DN (2014) A review: food and feeding habit of *Labeo calbasu* (Hamilton, 1822) from different habitat. Journal of the Kalash Science 2: 71–73.

Imteazzaman AM, Galib SM (2013) Fish fauna of Halti Beel. International Journal of Current Research 5: 187–190.

Islam MN, Kitazawa D (2013) Modeling of freshwater wetland management strategies for building the public awareness at local level in Bangladesh. Mitigation and Adaptation Strategies for Global Change 18: 869–888.

IUCN Bangladesh (2000) Red book of threatened fishes of Bangladesh. International Union for Conservation of Nature, Bangladesh Country Office, Dhaka, Bangladesh.

IUCN Bangladesh (2015) Red list of Bangladesh: a brief on assessment result 2015. Dhaka, Bangladesh, Bangladesh: International Union for Conservation of Nature, Bangladesh Country Office.

Jhingran VG (1997) Fish and fisheries of India. Hindustan Publishing Corporation, New Delhi, India.

Joadder MAR (2014) Seasonal occurrence of food and feeding habit of *Labeo bata* (Hamilton) (Cypriniformes : Cyprinidae). Journal of Science Foundation 12: 7–15.

Jones LA, Mandrak NE, Cudmore B (2017) Updated (2003-2015) biological synopsis of grass carp (*Ctenopharyngodon idella*). DFO Canadian Science Advisory Secretariat Research Document 2016/102. 64 pp.

Kennard MJ, Arthington AH, Pusey BJ, Harch BD (2005) Are alien fish a reliable indicator of river health? Freshwater Biology 50: 174–193.

Khaing MM, Khaing KYM, Lwin N (2019) Food and feeding habit of some freshwater fishes from Ayeyawady River, Myitkyina Township, KachinState, Myanmar. International Journal of Entomology Research 4: 96–100.

Khan AA (1993) Freshwater wetlands in Bangladesh: opportunities and options. In: Nishat A, Hussain Z, Roy MK, Karim A (Eds) Freshwater wetlands in Bangladesh—issues and approaches for management. IUCN, Dhaka, Bangladesh. pp. 1–8.

Kumar R, Sharma BK, Sharma LL (2007) Food and feeding habits of *Catla catla* (Hamilton-Buchanan) from Daya Reservoir, Udaipur, Rajasthan. Indian Journal of Agricultural Research 41: 266–269.

Laird CA, Page LM (1996) Non-native fishes inhabiting the streams and lakes of Illinois. Illinois Natural History Survey Bulletin 35: 1–57.

Latifa GA (2007) *Cirrhinus cirrhosus* (Bloch, 1795). In: Siddiqui KU, Islam MA, Kabir SMH, Ahmad M, Ahmed ATA, ... Rahman MM (Eds) Encyclopedia of flora and fauna of Bangladesh, volume 23. Freshwater Fishes. Asiatic Society of Bangladesh, Dhaka, Bangladesh. pp. 51–52.

Little TM, Hills FJ (1978) Agricultural experimentation. John Wiley & Sons, Ltd., New York, USA.
Lövei GL (1997) Global change through invasion. Nature 388: 627–628.
McNeely JA (2001) Invasive species: a costly catastrophe for native biodiversity. Land Use and Water Resources Research 1: 1–10.
Minkin SF, Rahman MM, Halder S (1997) Fish biodiversity and environmental restoration in Bangladesh. In: Tsai C, Ali MY (Eds) Openwater fisheries in Bangladesh. University Press Ltd., Dhaka, Bangladesh.
Mishra DK, Hussain SM (2012) Situation analysis on inland navigation, ecosystems for life: a Bangladesh-India initiative. IUCN- International Union for Conservation of Nature, Dhaka, Bangladesh.
Moyle PB, Leidy RA (1992) Loss of biodiversity in aquatic ecosystems: evidence from fish faunas. In: Fiedler PL, Jain SA (Eds) Conservation biology: the theory and practice of nature conservation, preservation, and management. Chapman and Hall, New York, USA. pp. 128–169.
Nahar N, Sultana N, Miah J (2018) Seasonal land cover changes and its effects on essential services of haor and non-haor areas of Kishoreganj district, Bangladesh. Asia-Pacific Journal of Regional Science 2: 399–429.
Narejo NT, Jalbani S, Khan P, Memon F (2016) Food and feeding habits of sting catfish *Heteropneustes fossilis* (Bloch) from Manchar Lake District Jamshoro Sindh Pakistan. Sindh University Research Journal (Science Series) 48(3): 473–476.
Paul SK (2005) Biology and culture management of shrimps. Monika Paul, Dhaka, Bangladesh (in Bengali).
Pimentel D, Mcnair S, Janecka J, Wightman J, Simmonds C, ... Tsomondo T (2001) Economic and environmental threats of alien plant, animal, and microbe invasions. Agriculture, Ecosystems & Environment 84(1): 1–20.
Rahman AKA (1989) Freshwater fishes of Bangladesh, first ed. Zoological Society of Bangladesh, Dhaka, Bangladesh.
Rahman AKA (2005) Freshwater fishes of Bangladesh, second edition. Zoological Society of Bangladesh, Dhaka, Bangladesh.
Rahman MK, Akhter JN (2015) Ecology and management of inland water and fishery resources of Bangladesh. Ideal Books, Dhaka, Bangladesh.
Ribeiro F, Elvira B, Collares-Pereira MJ, Moyle PB (2008) Life-history traits of non-native fishes in Iberian watersheds across several invasion stages: a first approach. Biological Invasions 10: 89–102.
Ross ST (1991) Mechanisms structuring stream fish assemblages: are there lessons from introduced species? Environmental Biology of Fishes 30: 359–368.
Sagoff M (2005) Do non-native species threaten the natural environment? Journal of Agricultural and Environmental Ethics 18: 215–236.
Salauddin M, Uddin AKMS (2011) Identification of land cover changes of the haor area of Bangladesh using MODIS images. 3rd International Conference on Water & Flood Management (ICWFM-2011).
Samad MA, Galib SM, Flowra FA (2009) Fish drying in Chalan Beel areas. Bangladesh Journal of Scientific and Industrial Research 44: 461–466.
Schmitt RJ (1987) Indirect interactions between prey: apparent competition, predator aggregation, and habitat segregation. Ecology 68: 1887–1897.
Shafi M, Quddus MMA (2001) Bangladesher matsho shampad (fisheries of Bangladesh). Kabir Publication, Dhaka, Bangladesh (in Bengali).
Siaw-Yang Y (1988) Food resource utilization partitioning of fifteen fish species at Bukit Merah Reservoir, Malaysia. Hydrobiologia 157: 143–160.
Strayer DL, Dudgeon D (2010) Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society 29(1): 344–358.
Suski CD, Cooke SJ (2007) Conservation of aquatic resources through the use of freshwater protected areas: opportunities and challenges. Biodiversity and Conservation 16: 2015–2029.
Tesfahun A, Temesgen M (2018) Food and feeding habits of Nile tilapia *Oreochromis niloticus* (L.) in Ethiopian water bodies: a review. International Journal of Fisheries and Aquatic Studies 6: 43–47.
Tsai C, Ali MY (1985) Open water fisheries (carp) management program in Bangladesh. Fisheries Information Bulletin (FAO) 2: 51.
Tsai C, Ali MY (1995) Open water fisheries of Bangladesh. The University Press Limited, Dhaka, Bangladesh.
van der Lee AS, Johnson TB, Koops MA (2017) Bioenergetics modelling of grass carp: estimated individual consumption and population impacts in Great Lakes wetlands. Journal of Great Lakes Research 43: 308–318.
Veale AJ, Holland OJ, McDonald RA, Clout MN, Gleeson DM (2015) An invasive non-native mammal population conserves genetic diversity lost from its native range. Molecular Ecology 24: 2156–2163.
Welcomme RL (1979) Fisheries ecology of floodplain rivers. Longman Group Ltd., London. UK.
Welcomme RL (1988) International introductions of inland aquatic species. FAO Fisheries Technical Paper 294. Rome, Italy.
Williamson M (1996) Biological invasions. Population and community biology series 15, first edition. Chapman & Hall, London, UK.
Yi Y, Diana JS, Shrestha MK, Lin CK (2004) Culture of mixed-sex Nile tilapia with predatory snakehead. In:

Bolivar R, Mair G, Fitzsimmons K (Eds) The 6th International Symposium of Tilapia in Aquaculture. Manila, Philippines.

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