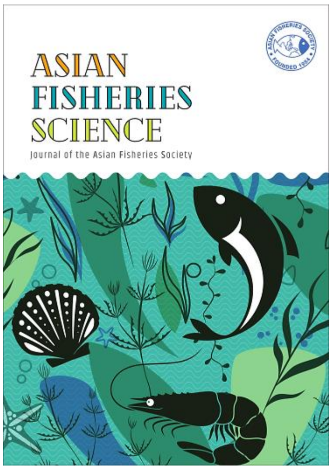

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Production Trends, and Challenges for Biodiversity Conservation and Sustainable Fisheries Management of Kaptai Lake, the Largest Reservoir in Bangladesh

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Abstract

Kaptai Lake (KL), the largest artificial lake in Bangladesh, supports an important inland open water fishery. Nevertheless, detailed studies on its fish diversity and environmental threats are still limited. Hence, a study was conducted to evaluate the current fish management scenarios, fish production, relative abundance to improve the production and biodiversity of KL. Data were collected from stakeholders through personal observation, focus group discussions, and cross-check interviews from September 2018 to July 2019. The fish production of KL increased from 1,200 metric tons (MT) in 1965–1966 to 10,577 MT in 2018–2019. The output of the lake was dominated by small fish remarkably, *Gudusia chapra* (Hamilton, 1822), *Gonialosa manmina* (Hamilton, 1822), and *Corica soborna* Hamilton, 1822, accounting for 64 % of the total production in 2018–2019. A total of seventy-six fish species were observed under ten orders, including seven exotic fish species. According to the IUCN Bangladesh, 14 % of total species were identified as vulnerable, 11 % as endangered, 3 % as critically endangered, 11 % as near threatened and 51 % as least concern. The study also identified that climate change and various human-driven causes threaten the fish production and biodiversity of this lake. These findings suggest that community-based fisheries management, protection of natural breeding grounds of carps, control of pollution, amendment of existing fishing laws, and collaborative research would be a necessary approach for mitigating the negative environmental impact of this lake. The overall practical knowledge of this investigation could assist in policymaking and further research.

Keywords: management, threats, fish production, biodiversity, conservation

Introduction

Inland fisheries are an important source of protein for Bangladesh. With a shortage of land available for livestock and other food production systems, freshwater bodies are increasingly crucial for fish production as a means of meeting the demand for protein-based food in Bangladesh (Sunny et al., 2020). Artificial lakes are increasingly utilised in Asia for aquaculture and wild capture fisheries (IUCN Bangladesh, 2015a). The H-shaped Kaptai Lake (KL) is the largest artificial freshwater lake in South East Asia. The lake was constructed in 1961 to produce hydroelectricity by damming the River Karnaphuli at Kaptai in the Chittagong Hill Tracts of Bangladesh. The lake's total area is 68,800 hectares (ha), with a water surface area of 58,300 ha. The impoundment created a valuable inland fisheries resource for Bangladesh (Ahmed et al., 2006, IUCN Bangladesh, 2015a). The impoundment involved flooding the middle Karnaphuli Valley and the lower water streams of the Chengi, Kasalong and Rinkhyong rivers of Chittagong. The main flow of the lake is formed nearby in the hill districts of Rangamati (Fig. 1). The maximum depth is approximately 150 m, while the average depth is 30 m (IUCN Bangladesh, 2015b). The lake shoreline is rocky and filled with submerged dead trees and wooden logs, which act as barriers to fishing and navigation (Ahmed et al., 2003).

The current fish production of the lake is 10,152 metric tons (MT) (0.24 % of total fish production) while the country's total fish production is 4.277 million MT (DoF, 2018). Though the main purpose of the lake is hydroelectricity production, it also contributes to the GDP through freshwater fish production, water transportation, flood control, tourism, and irrigation (Bashar et al., 2015; IUCN Bangladesh, 2015b). The lake is rich in fish diversity and contains 74 fish species, including six exotic fish species, which support small-scale fisheries for the surrounding inhabitants (Chakma, 2007). Both fish culture and capture in KL are monitored and controlled by the Bangladesh Fisheries Development Corporation (BFDC).

The gradual trend in biodiversity reduction is one of the major challenges for sustainable management of most of the wetlands of Bangladesh. This results in indiscriminate exploitation of fisheries resources by the fishing communities to support their livelihoods (Sunny et al., 2020). The environment and aquatic organisms of the KL experience various natural and anthropogenic pressures. Regular landslides and a high sediment load from the inflowing rivers negatively affect the habitat of aquatic organisms and biodiversity. Siltation has reduced 25 % of the lake volume over the last 30 years (IUCN Bangladesh, 2015b). Surrounding human communities depend on the lake for social, economic, and cultural benefits (Haldar et al., 2003). All these activities ultimately affect the fish biodiversity of KL. Therefore, this lake's biodiversity has declined over the past years, resulting in the loss of eight fish species and the threatening existence of another eight species (Halder et al., 1991). There have been many studies on the socio-economic value of KL (Ahmed et al., 2006), the impact of fish polyculture (Ahmed et al., 2002; Alamgir and Ahmed, 2005; Bashar et al., 2014; Basak et al., 2017), fish harvesting methods (Ahmed and Hambrey, 1999; Kabir et al., 2020), and limnological and biological aspects of the lake (Borre et al., 2001; Rahman et al., 2014; Bashar et al., 2015). However, detailed studies on the threats, fish production trends and fish diversity status of the KL are lacking. Therefore, this study explores the present trends of fish production, biodiversity status and threats to fish species.

Materials and Methods

Study area and data collection

The present study was conducted from September 2018 to July 2019 at KL (latitude 22°20'-23°18' N; longitude 92°00'-92°26' E) in Bangladesh, as shown in Figure 1. The present investigation collected primary and secondary data using the following methods.

Direct observation

The fish catch and species composition were assessed through field monitoring. A catch assessment survey was conducted to calculate total fish production (catch) based on the amount of fish caught per day at different landing stations of BFDC, Rangamati. The specimens were collected during the daytime, and precautions (safe handling of fish from catching to landing sites, immediate and proper icing) were taken to save specimens from spoilage or any damage. Boats and steamers were mainly used to transport nets and related materials. Seine nets, cast nets, drag nets, and lift nets were used depending on the season and availability of different fish species. The water temperature of KL was recorded by a portable digital Celsius thermometer, dissolved oxygen (DO) measured by a portable digital DO meter (PDO-519, Lutron, Taiwan) and pH using a pH meter (HI 8428, Hanna, USA).

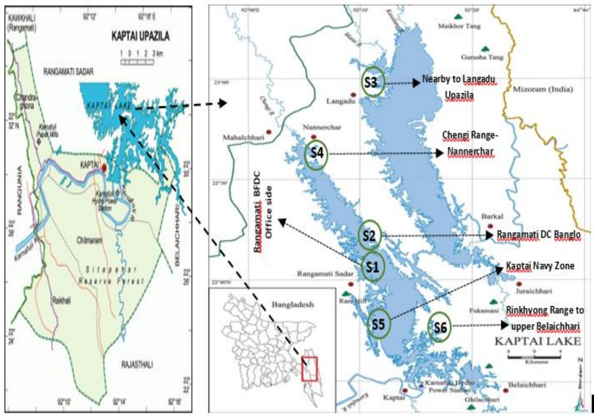

Fig. 1. Map showing the Kaptai Lake, Bangladesh, indicating six sanctuaries. S1: Rangamati near Bangladesh Fisheries Development Corporation Office; S2: Rangamati Deputy Commissioner bungalow; S3: nearby Langadu Upazila; S4: Chengi Range-Nannerchar; S5: Kaptai Navy Zone; S6: Rinkhyong Range to upper Belaichhari.

Focus group discussion and key informant interviews

A structured questionnaire was used to gather specific fisheries data, including fish species, their abundance with the season, changes in fish species availability, effects of climate change, water pollution, encroachment of lake area, illegal fishing practice. Whereas focus group discussions were held at fish landing centres (BFDC main pontoon Rangamati, Kaptai fish landing centre and Mahalchhari fish landing centre), fish markets nearby KL and local fishers' village. Fish traders (aratdar), middleman, retailer, fishers, and local residents were interviewed. The applied questionnaire is shown in Appendix 1. The number of respondents who answered the survey based on Appendix 1 was 110. However, the participants who shared their views at different times about the KL fishery management and fish biodiversity were more than 1000 people. Among the 110 respondents, 40 were fishers, 30 fish traders, 15 middlemen, 15 fish retailers and 10 were local villagers.

Specimen identification and composition

Fish species were collected from fishing vessels in different landing centres and fish market from the study area. They were preserved in 5–7 % buffered formalin for long-term preservation and identified based on their morphometric and meristic characteristics as Rahman (2005) and followed by FishBase (2020). Moreover, the finfish and shellfish were systematically classified into different orders, including Cypriniformes, Siluriformes, Perciformes, Clupiformes, Synbranchiformes, Beloniformes, Mugiliformes, Tetraodontiformes, Osteoglossiformes and Decapoda based on Nelson's (2006) classification.

Total catch was estimated by:
Catch (total) = CPUE * Effort
where,
Catch (total): Refers to all species collected and generally estimated within a particular area, a defined time and/or a specific boat/gear category.
CPUE (catch per unit effort): Quantity of fish is caught by unit effort.
Effort: Determined uniformly in total number of boat-days within the same logical context used for total catch and overall CPUE.

Relative abundance of fish

Relative abundance of fish was measured following Jadhav et al. (2011) with slight modification, i.e., very common (>75 % of the total catch), common (50–75 % of the total catch), few (25–50 % of the total catch), rare (10–25 % of the total catch), and very rare (<10 % of the total catch). The relative abundance was estimated depending on the availability of a particular fish species in a total catch during harvesting from a fishing vessel. The process generates 'fishery dependent data', which is an important tool for fisheries researchers to properly manage the aquatic resources (Pennino et al., 2016).

Results

Present trends of fish production

During the last 11 years, the highest fish yield was recorded in 2018-19 (10,577 MT) and the lowest found in 2008–2009 (5,578 MT) (Fig. 2). Among the total fish production, 70 % of fish is landed in the three landing centres of BFDC, and the remaining 30 % of fish is distributed and sold in the local markets adjacent to the lake. Under BFDC supervision, commercial fishing in KL commenced with 1,200 MT in 1965–1966 and reached 4,556 MT by 2002–2003 (Alamgir and Ahmed, 2005; Ahmed et al., 2006). Over five decades, the total fish production from this lake increased remarkably; the production capacity reached 123 $kg.ha^{-1}$ in 2011–2012, 148 $kg.ha^{-1}$ in 2017–2018, and 181.42 $kg.ha^{-1}$ in 2018–2019.

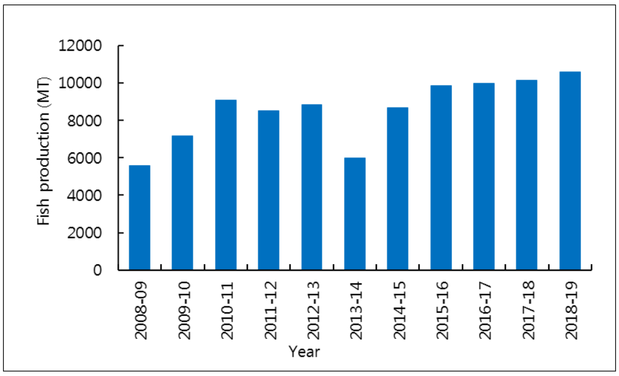

Fig. 2. The trend of fish production during 2008–2009 to 2018–2019 in Kaptai Lake, Bangladesh.

Although total fish production from the lake has increased significantly from 1965–1966 to 2018–2019, mainly contributed by; i) Ganges river gizzard shad (*G. manmina*), and Indian river shad (*G. chapra*), ii) other small indigenous fish species which can grow to maximum of 25 cm at maturity, regarded as small indigenous fish species (SIS) notably, *C. soborna*, iii) two species of carplet, the Indian carplet *Amblypharyngodon microlepis* (Bleeker, 1853), mola carplet *Amblypharyngodon mola* (Hamilton, 1822), iv) bata *Labeo bata* (Hamilton, 1822), and v) Gangetic ailia *Ailia coila* (Hamilton, 1822) (Table 1). Major fish species/groups from which maximum fish production of the lake was formed in the past 11 years are listed as (1) Indian river shad (*G. chapra*) and Ganges river gizzard shad (*G. manmina*), (2) Ganges river sprat (*C. soborna*), (3) carplet (*A. microlepis* and *A. mola*), (4) long-whiskered catfish *Sperata aor* (Hamilton, 1822), (5) Gangetic ailia (*A. coila*), and (6) bata (*L. bata*) (Fig. 3).

The alarming issue is the drastic reduction of the Indian major carps (IMC), (*Labeo calbasu* (Hamilton, 1822), *Gibelion catla* (Hamilton, 1822), *Labeo rohita* (Hamilton, 1822), *Cirrhinus cirrhosis* (Bloch, 1795)), and other native carps (*Labeo gonius* (Hamilton, 1822), and *L. bata* (Hamilton, 1822)). In 2018–2019, *C. soborna*, *G. manmina* and *G. chapra* together contributed 63.76 %, two species of carplet (*A. microlepis* and *A. mola*) 3.01 % of the total fish production, whereas different carp species (*L. calbasu*, *G. catla*, *L. rohita*, *C. cirrhosis*, *L. gonius*, and *L. bata*) contributed only 1.56 % of the total fish yield from the lake (Table 1). However, in 1965–1966 the above-mentioned carp species accounted for 81 % of the total fish production, and only 3 % were from *G. manmina*, *G. chapra*, *Ompok pabda* (Hamilton, 1822), and *Ompok bimaculatus* (Bloch, 1794), together (Table 1).

Fish species composition, diversity, and conservation status

A total of 76 fish species under 10 orders, including 30 commercially valuable species, 7 prawn, and 2 crab species, were recorded from the lake. Among these, 7 exotic fish species and 9 shellfish species belonging to order Decapoda were recorded during the study period (Table 2). Cypriniformes was the most dominant order contributing 26 species following the order Siluriformes with 15 species. Fourteen species

Table 1. Trends of total fish production in Kaptai Lake from 1965–1966 to 2018–2019.

Year	Total production (MT)	Production capacity (kg.ha^{-1})	Contribution of major species in total production	References
2018–2019	10,577	181.42 [1]Ganges river gizzard shad, [2]Indian river shad and [3]Ganges river sprat: 115.68 [4]Carplet: 5.46 [5]Carp: 2.83	Ganges river gizzard shad, Indian river shad and Ganges river sprat: 63.76 % Carplet: 3.01 % Carp: 1.56 %	Present study
2007–2008	8,248	141.28	Carp: 4 % Ganges river sprat, Ganges river gizzard shad, Indian river shad, Pabdah catfish and Butter catfish: 92 %	Bashar et al., 2014; Bashar et al., 2015
2000–2001	4,751	81.5 Ganges river gizzard shad, Indian river shad and Ganges river sprat: 32	Ganges river gizzard shad, Indian river shad and Ganges river sprat: 63.4 %; Carp: 5.1 %	Ahmed et al., 2006
1998–1999	-	-	Ganges river gizzard shad, Indian river shad and Ganges river sprat: 65.0 % Carp: 6.42 %	Ahmed et al., 2003
1965–1966	1,200	20.58	Carp: 81 %; Ganges river gizzard shad, Indian river shad, Ganges river sprat, [6]Pabda catfish and [7]Butter catfish: 3 %	Ahmed et al., 2006; Alamgir and Ahmed, 2005

[1]Ganges river gizzard shad (*Gonialosa manmina*), [2]Indian river shad (*Gudusia chapra*), [3]Ganges river sprat (*Corica soborna*), [4]carplet (*Amblypharyngodon microlepis*, *Amblypharyngodon mola*), [5]Carp (*Labeo calbasu*, *Gibelion catla*, *Labeo rohita*, *Cirrhinus cirrhosis*, *Labeo gonius*, *Labeo bata*), [6]Pabdah catfish (*Ompok pabda*), [7]Butter catfish (*Ompok bimaculatus*).

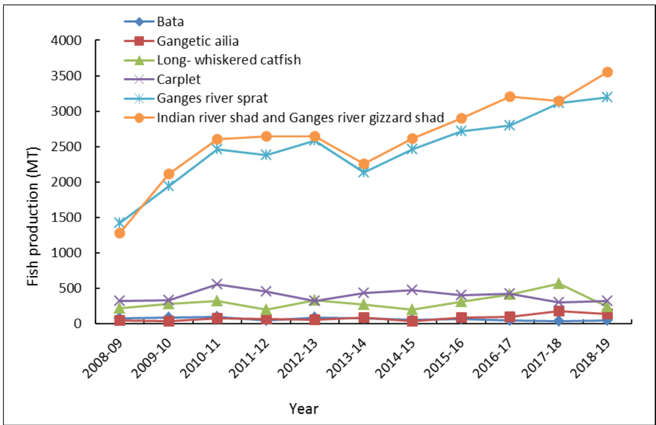

Fig. 3. Major fish species/groups contributing to the total production from 2008–2009 to 2018–2019 in the Kaptai Lake, Bangladesh.

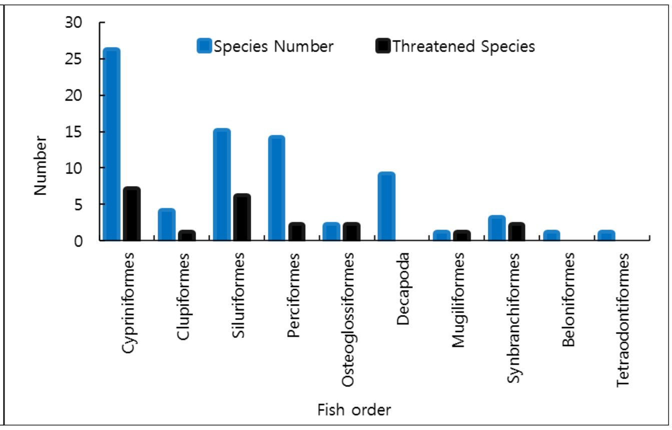

Fig. 4. Number of total and threatened fish species based on fish order observed in the Kaptai Lake, Bangladesh. (Source: IUCN Bangladesh, 2015a, b).

were found in the order Perciformes while four, three, and two species were recorded in the orders Clupiformes, Synbranchiformes, and Osteoglossiformes, respectively. Only one species was found under each order of Beloniformes, Mugiliformes, and Tetraodontiformes (Fig. 4; Table 2).

Cypriniformes was recorded as the most diversified fish group. The exotic fishes *Hypophthalmichthys molitrix* (Valenciennes, 1844), *Ctenopharyngodon idella* (Valenciennes, 1844), *Cyprinus carpio* Linnaeus, 1758, *Hypophthalmichthys nobilis* (Richardson, 1845), *Clarias gariepinus* (Burchell, 1822), *Oreochromis mossambicus* (Peters, 1852), and *Oreochromis niloticus* (Linnaeus, 1758) were introduced into the KL intentionally or unintentionally from the nearby aquaculture ponds and hatcheries. According to IUCN Red List, a total of twenty-one and five fish species have been recorded from the present study considered threatened (vulnerable, endangered, and critically endangered) in the perspective of IUCN Bangladesh and IUCN Global status respectively (Table 2).

It is alarming that among 64 freshwaters threatened fish species of Bangladesh, 21 species (7 species of Cypriniformes, 6 species of Siluriformes, 2 species

Table 2: Fish species composition with their relative abundance and IUCN conservation status (Bangladesh and global perspective) recorded in the Kaptai Lake, Bangladesh.

No.	Common name	Scientific name	IUCN conservation status		Relative abundance[3]
			Bangladesh[1]	Global[2]	
Order: Cypriniformes					
01	Roho labeo	*Labeo rohita* (Hamilton,1822)	LC	LC	VC
02	Catla	*Gibelion catla* (Hamilton, 1822)	LC	LC	VC
03	Mrigal carp	*Cirrhinus cirrhosus* (Bloch, 1795)	NT	VU	VC
04	Finescale razorbelly minnow	*Salmostoma phulo* (Hamilton, 1822)	NT	DD	R
05	Cotio	*Osteobrama cotio* (Hamilton, 1822)	NT	LC	R
06	Silver carp	*Hypophthalmichthys molitrix* (Valenciennes, 1844)	*EX	NT	C
07	Grass carp	*Ctenopharyngodon idella* (Valenciennes, 1844)	*EX	DD	VC
08	Bata	*Labeo bata* (Hamilton, 1822)	LC	LC	VC
09	Reba carp	*Cirrhinus reba* (Hamilton, 1822)	NT	LC	VR
10	Indian flying barb	*Esomus danrica* (Hamilton, 1822)	DD	LC	R
11	Olive danio	*Danio dangila* (Hamilton, 1822)	VU	LC	VR
12	Stone roller	*Crossocheilus latius* (Hamilton, 1822)	EN	LC	R
13	Morari	*Cabdio morar* (Hamilton, 1822)	VU	LC	VR
14	Tor mahseer	*Tor tor* (Hamilton, 1822)	CR	DD	VR
15	Olive barb	*Systomus sarana* (Hamilton, 1822)	NT	LC	VR
16	Pool barb	*Puntius sophore* (Hamilton, 1822)	LC	LC	VR
17	Common carp	*Cyprinus carpio* Linnaeus, 1758	*EX	VU	R
18	Kuria labeo	*Labeo gonius* (Hamilton, 1822)	NT	LC	F
19	Ticto barb	*Pethia ticto* (Hamilton, 1822)	VU	LC	F
20	Onespot barb	*Puntius terio* (Hamilton, 1822)	LC	LC	F
21	Bighead carp	*Hypophthalmichthys nobilis* (Richardson, 1845)	*EX	DD	F
22	Carplet (Indian carplet)	*Amblypharyngodon microlepis* (Bleeker, 1853)	LC	LC	VC
23	Carplet (Mola carplet)	*Amblypharyngodon mola* (Hamilton, 1822)	LC	LC	VC
24	Bengal loach	*Botia dario* (Hamilton, 1822)	EN	LC	R
25	Orangefin labeo	*Labeo calbasu* (Hamilton, 1822)	LC	LC	VC
26	Annaldale loach	*Lepidocephalichthys annandalei* Chaudhuri, 1912	VU	LC	R
Order: Clupiformes					
27	Ganges river gizzard shad	*Gonialosa manmina* (Hamilton, 1822)	LC	LC	VC
28	Indian river shad	*Gudusia chapra* (Hamilton, 1822)	VU	LC	VC
29	Ganges river sprat	*Corica soborna* Hamilton, 1822	LC	LC	VC
30	Gangetic hairfin anchovy	*Setipinna phasa* (Hamilton, 1822)	LC	LC	VR
Order: Siluriformes					
31	Long- whiskered catfish	*Sperata aor* (Hamilton, 1822)	VU	LC	VC
32	Pabdah catfish	*Ompok pabda* (Hamilton, 1822)	EN	NT	C
33	Butter catfish	*Ompok bimaculatus* (Bloch, 1794)	EN	NT	C
34	Indian patasi	*Pachypterus atherinoides* (Bloch, 1794)	LC	LC	R
35	Wallago	*Wallago attu* (Bloch & Schneider, 1801)	VU	VU	VC
36	Gangetic ailia	*Ailia coila* (Hamilton, 1822)	LC	NT	VC
37	Striped dwarf catfish	*Mystus vittatus* (Bloch, 1794)	LC	LC	F
38	Tengara catfish	*Mystus tengara* (Hamilton, 1822)	LC	LC	VC
39	Goonch	*Bagarius bagarius* (Hamilton, 1822)	CR	NT	VR
40	Day's mystus	*Mystus bleekeri* (Day, 1877)	LC	LC	F

Table 2. Continued.

No.	Common name	Scientific name	IUCN conservation status		[3]Relative abundance
			[1]Bangladesh	[2]Global	
41	Pangas catfish	*Pangasius pangasius* (Hamilton, 1822)	EN	LC	R
42	Batchwa vacha	*Eutropiichthys vacha* (Hamilton, 1822)	LC	LC	C
43	Stinging catfish	*Heteropneustes fossilis* (Bloch, 1794)	LC	LC	VC
44	North African catfish	*Clarias gariepinus* (Burchell, 1822)	*EX	LC	R
45	Philippine catfish	*Clarias batrachus* (Linnaeus, 1758)	LC	LC	R
Order: Perciformes					
46	Mozambique tilapia	*Oreochromis mossambicus* (Peters, 1852)	*EX	VU	F
47	Nile tilapia	*Oreochromis niloticus* (Linnaeus, 1758)	*EX	LC	C
48	Tank goby	*Glossogobius giuris* (Hamilton, 1822)	LC	LC	VR
49	Gangetic leaffish	*Nandus nandus* (Hamilton, 1822)	NT	LC	R
50	Badis	*Badis badis* (Hamilton, 1822)	NT	LC	R
51	Scribbled goby	*Awaous personatus* (Bleeker, 1849)	VU	LC	VR
52	Dwarf gourami	*Trichogaster lalius* (Hamilton, 1822)	LC	LC	F
53	Banded gourami	*Trichogaster fasciata* Bloch & Schneider, 1801	LC	LC	F
54	Climbing perch	*Anabas testudineus* (Bloch, 1792)	LC	LC	F
55	Elongate glass-perchlet	*Chanda nama* Hamilton, 1822	LC	LC	R
56	Striped snakehead	*Channa striatus* (Bloch, 1793)	LC	LC	F
57	Great snakehead	*Channa marulius* (Hamilton, 1822)	EN	LC	F
58	Spotted snakehead	*Channa punctatus* (Bloch, 1793)	LC	LC	VC
59	Walking snakehead	*Channa orientalis* Bloch & Schneider, 1801	LC	VU	VR
Order: Mugiliformes					
60	Yellowtail mullet	*Minimugil cascasia* (Hamilton, 1822)	VU	LC	VR
Order: Beloniformes					
61	Freshwater garfish	*Xenentodon cancila* (Hamilton, 1822)	LC	LC	R
Order: Synbranchiformes					
62	Cuchia	*Monopterus cuchia* (Hamilton, 1822)	VU	LC	F
63	Zig-zag eel	*Mastacembelus armatus* (Lacepède, 1800)	EN	LC	C
64	Barred spiny eel	*Macrognathus pancalus* Hamilton, 1822	LC	LC	F
Order: Tetraodontiformes					
65	Ocellated pufferfish	*Leiodon cutcutia* (Hamilton, 1822)	LC	LC	VR
Order: Osteoglossiformes					
66	Clown knifefish	*Chitala chitala* (Hamilton, 1822)	EN	NT	C
67	Bronze featherback	*Notopterus notopterus* (Pallas, 1769)	VU	LC	VC
Order: Decapoda					
68	Giant freshwater prawn	*Macrobrachium rosenbergii* (de Man, 1879)	LC	LC	C
69	Monsoon river prawn	*Macrobrachium malcolmsonii* (H. Milne Edwards, 1844)	LC	LC	C
70	Short-leg river prawn	*Arachnochium mirabile* (Kemp, 1917)	LC	LC	VC
71	Birma river prawn	*Macrobrachium birmanicum* Schenkel, 1902	LC	LC	VC
72	Karnafuli shrimp	*Nematopalaemon karnafuliensis* (Ali Azam Khan, Fincham & Mahmood, 1980)	LC	LC	VC
73	Giant tiger shrimp	*Penaeus monodon* Fabricius, 1798	LC	NE	R
74	Indian white shrimp	*Penaeus indicus* H. Milne Edwards, 1837	LC	NE	R
75	Giant mud crab	*Scylla serrata* (Forskål, 1775)	LC	NE	C
76	Orange mud crab	*Scylla olivacea* (Herbst, 1796)	LC	NE	C

[1]IUCN Bangladesh (2015a, b)

[2]IUCN Global 2020

Conservation status: CR (critically endangered), DD (data deficient), EN (endangered), LC (least concern), NE (not evaluated), NT (near threatened), VU (vulnerable), *EX (exotic)

[3]Relative abundance: VR (very rare), R (rare), F (few), C (common), VC (very common)

from each of the order of Osteoglossiformes, Perciformes and Synbranchiformes, one species each of the order Clupiformes and Mugiliformes) were identified as threatened in KL (Fig. 4). Among 21 threatened fish species, there were 11 classed as vulnerable (VU), 8 endangered (EN), and 2 critically endangered (CR) species (Fig. 5; Table 2). Among the threatened fish species, *Chitala chitala* (Hamilton, 1822), *Mastacembelus armatus* (Lacepède, 1800), *Channa marulius* (Hamilton, 1822), *Pangasius pangasius* (Hamilton, 1822), *O. bimaculatus*, *O. pabda*, *Botia dario* (Hamilton, 1822), *Crossocheilus latius* (Hamilton, 1822), were identified as endangered, while two fish species *Tor tor* (Hamilton, 1822), and *Bagarius bagarius* (Hamilton, 1822), were recorded as critically endangered in the context of Bangladesh. However, in the global context, some threatened fish species including, *C. cirrhosis*, *Wallago attu* (Bloch & Schneider, 1801), *H. molitrix*, *O. pabda*, *O. bimaculatus*, *A. coila* and *C. chitala* may not be threatened for this lake, as they are available in sufficient numbers throughout the year. All these fish belonged to vulnerable (11) 14 %, endangered (8) 11 %, near threatened (NT) (8) 11 %, critically endangered (2) 3 %, and data deficient (1) 1 % classes, while VU (5) 7 %, NT (6) 8 %, DD (4) 5 % and NE (4) 5% as Bangladesh and Global perspective, respectively. Most fish belonged to the least concern (LC) category, i.e., 39 (51 %) and 57 (75 %) in terms of IUCN Bangladesh and IUCN Global, respectively (Fig. 5; Table 2).

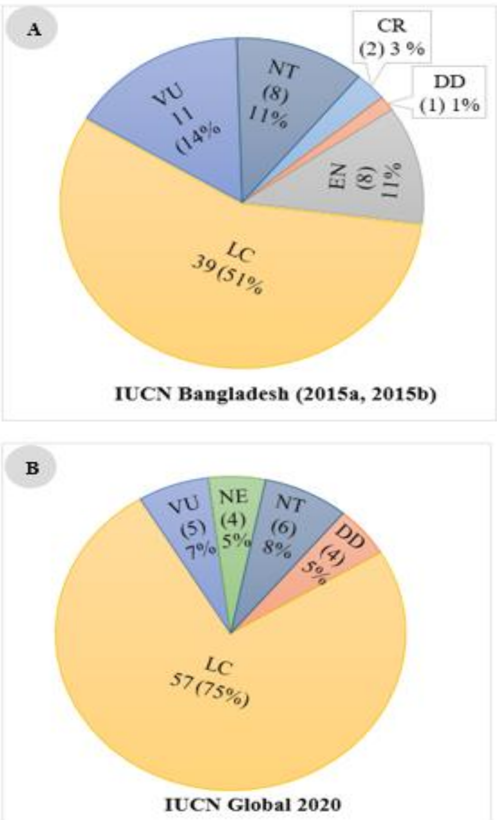

Fig 5. Conservation status of the fish species recorded in Kaptai Lake, Bangladesh based on, A) IUCN Bangladesh and B) IUCN Global; CR - critically endangered, DD - data deficient, EN - endangered, LC - least concern, NE - not evaluated, NT - near threatened, VU -vulnerable.

Relative abundance of fish species

A total of 76 fish species were categorised into five major groups depending on their relative abundance, such as very common (21) 28 %, common (12) 16 %, few (14) 18 %, rare (16) 21 % and very rare (13) 17 % (Fig. 6). Among the fish species categorised as 'very common' were *G. chapra*, *C. soborna*, *S. aor*, *L. rohita*, *L. calbasu*, *Mystus tengara* (Hamilton, 1822), *Channa punctatus* (Bloch, 1793), *A. mola*, *Macrobrachium birmanicum* (Schenkel, 1902), *Nematopalaemon karnafuliensis* (Ali Azam Khan, Fincham and Mahmood, 1980), *L. calbasu*, *W. attu*, *A. coila*, and *L. bata*. Similar observations were reported by Kabir et al. (2020). On the other hand, the abundance of *Cirrhinus reba* (Hamilton, 1822), *T. tor*, *Puntius sarana* (Hamilton, 1822), *Setipinna phasa* (Hamilton, 1822), *B. bagarius*, *Glossogobius giuris* (Hamilton, 1822), and *Channa orientalis* Bloch and Schneider, 1801 was in decline (very rare) (Table 2). The rapid reduction and less abundance of these fish species might result from over-exploitation, habitat degradation, severe pollution, climate change, conversion and complete drying up of wetlands. These factors are also the main causes of the reduction of freshwater fish diversity and total fish production in Bangladesh (IUCN Bangladesh, 2015a). Among the exotic species, *H. molitrix*, *C. idella*, *O. mossambicus*, and *O. niloticus* were abundant than other species.

Among the threatened fish species, *Notopterus notopterus* (Pallas, 1769), *W. attu*, *S. aor*, and *G. chapra* were categorised as 'very common'; *C. chitala*, *M. armatus*, *C. marulius*, *O. bimaculatus*, and *O. pabda* as 'common', while *Monopterus cuchia* (Hamilton, 1822), categorised as 'few' during the study period. The abundance of these fish species infers that these fish may not be threatened in this lake, although threatened in the broader context of IUCN Bangladesh.

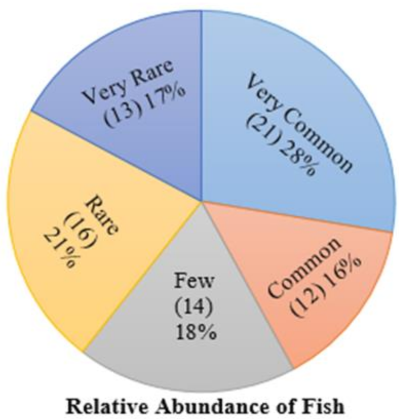

Fig. 6. The relative abundance of fish based on the availability of a particular fish species in a total catch during harvesting in the Kaptai Lake, Bangladesh. Very common: >75 % of the total catch; Common: 50–75 % of the total catch; Few: 25–50 % of the total catch; Rare: 10–25 % of the total catch; Very rare: <10 % of the total catch.

Threats to Kaptai Lake and biodiversity

Water pollution

The KL water has been reported unsuitable for drinking and domestic use due to the presence of pathogenic microbes (*Enterococcus* spp., *Salmonella* spp., *Pseudomonas* spp. and *Vibrio* spp.) as well as excess concentrations of toxic metals, i.e., lead, cadmium, and nickel (Barua et al., 2016). The Halda River, adjacent to KL, is considered a unique breeding ground for carp in South East Asia and has already lost 26 of its fish species (Bashar et al., 2007; Bhuyan and Bakar, 2017) due to chronic water pollution caused by municipal sewage, industrial and agricultural waste either directly discharged into the river or by seepage and runoff (Karim et al., 2019; Moula et al., 2020). Such pollution leads to frequent eutrophication, excessive turbidity, oxygen depletion in many parts of KL, and the sudden death of fish observed during the study period.

Illegal structures

Many illegal facilities and activities occur within the catchment of KL, including the construction of houses, industrial-scale factories, unplanned irrigation channels, and water diversion channels for hydroelectricity that have degraded fish habitat and breeding grounds.

Increase of non-native fish intrusion and small indigenous fish species

During the study period, seven exotic species were identified (Table 2). Their establishment in natural and semi-natural water bodies as an invasive alien species could predate native fish species, alter the food web, disease outbreaks, and competition for food and space (IUCN Bangladesh, 2015b; Sheath et al., 2015). Moreover, the extensive growth of *C. soborna, G. manmina* and *G. chapra* (originally marine fish) imposed a key ecological challenge in the species composition of the KL (Ahmed et al., 2006).

Illegal, unreported, and unregulated fishing

More than 2000 small and large fish aggregating devices (FAD), including net fencing with bamboo, brush fishery, were reported during this study (Fig. 7). These are liable to the post-stocking reduction of carp fingerlings in the lake (Ahmed and Hambrey, 1999). The use of destructive fishing gear, fishing by dewatering creeks, harvesting of undersized fish, catching fish during banned periods, overfishing, and poaching fish were observed as common issues.

Uncontrolled soil and sand withdrawal

Unregulated use of soil from the bank of the lake and mass removal of sand and supporting vegetation have resulted in destabilisation of rocky hills and soil erosion and, thus, frequent landslides leading to blockages and siltation of the lake. The lake had already experienced a 25 % loss of its total volume due to siltation (IUCN Bangladesh, 2015b).

Proliferation of water hyacinth

Water hyacinth native to South America is now regarded as one of the noxious aquatic weeds available in temperate, tropical, and sub-tropical countries, including Bangladesh (Ndimele, 2012). Mass accumulation of this weed harbour harmful microbes, reptiles and venomous snakes and significantly hamper navigation, tourism, and fisheries (Patel, 2012; Ndimele, 2012). Similarly, the mass- and rapid growth of water hyacinth and their extensive usage as brush fishery to lure all types of fish over the last two decades has negatively impacted KL fishery.

Effects of climate change

Climate change, resulting in increased water temperature, is responsible for DO depletion, cyano-bacterial blooms, and thus rapid outbreak of fish disease (Brander, 2007). Fish biodiversity of KL was heavily disturbed through fluctuation in water flow,

Fig. 7. Destructive fishing practices threatening fish biodiversity of Kaptai Lake, Bangladesh. A: Illegal encroachment of the lake waterbody by settlers; B: Net fencing with bamboo; C: Rapid proliferation of water hyacinth and their usage as fish aggregating device; D: Harmful brush fishery.

temperature rise, shoreline siltation, the rise of char (silt bed), lack of rainfall and thunderstorms during breeding time, seasonal variations, and changes in fish migration routes because of global climate change. These threats resemble the findings of Borre et al. (2001), Ahmed et al. (2006), and Sunny et al. (2020).

Discussion

Fish landing centre is an important source for quick and smooth disposal of fresh fish. In this study, the fish landing centres of BFDC were considered one of the main sources of observation to survey the status of fish, source of fish and availability. The study revealed that the fish production of KL varies from year to year. Over the last 11 years, the maximum fish yield was recorded in 2018–2019 and the minimum found in 2008–2009 (Fig. 2). The majority of fish (about 70 % of total fish yield) were landed in the three landing centres of BFDC, while the highest amount of fish in the number of species and quantity was recorded in the Rangamati fish landing centre and lowest in the Mahalchhari fish landing centre. These are due to better infrastructure, icing facilities, good communication systems and closeness of the Rangamati main city to Rangamati fish landing centre than other landing centres. These statistics were consistent with Basak et al. (2017). Though total fish production is increasing gradually, this production capacity is less compared to the production capacity of river and estuary (376 kg.ha^{-1}) and floodplain fisheries (283 kg.ha^{-1}) (DoF, 2018). River denotes the large natural flow of fresh water with a particular course or series of diverging and converging channels and usually finds its way into sea, ocean, and lake. The estuary is a transition area between rivers and marine environments. A floodplain is any land area near a stream or river that becomes inundated during the monsoon season (Rahman et al., 2010, DoF, 2018). The reduction of KL fish production capacity could be attributed to the overexploitation of undersized fish, degradation of natural fish habitat, and pollution of the lake, which were demonstrated in the previous investigation by Ahmed et al.) (2006). Currently, a major portion of the total yield is contributed by the following fish species, Ganges river gizzard shad (*G. manmina*), Indian river shad (*G. chapra*), Ganges river sprat (*C. soborna*), carplet (*A. microlepis*, *A. mola*), long-whiskered catfish (*S. aor*), Gangetic ailia (*A. coila*), and bata (*L. bata*) (Fig. 3). In 2018–2019, 63.76 % of the total fish production were from *C. soborna*, *G. manmina* and *G. chapra*, whereas only 1.56 % from several carp species (*L. calbasu*, *G. catla*, *L. rohita*, *C. cirrhosis*, *L. gonius*, *L. bata*). However, 81 and 3 % of the total fish production in 1965–1966 were produced from the above-mentioned carp species and small fish species (*C. soborna*, *G. manmina*, *G. chapra*, *O. pabda*, and *O. bimaculatus*), respectively (Table 1).

This alteration in species variation could be due to early maturity and high recruitment ability of SIS under polluted environmental conditions of floodplain lakes (Mondal and Kaviraj, 2010). Haque et al. (1999) reported an excessive abundance of *C. soborna, G. manmina* and *G. chapra* in oxbow lakes in the south-western region of Bangladesh due to their prolific breeding and high growth rate. Moreover, seasonal bans on small-sized fishing also promote their proliferation. Thus, mass production of clupeids, SIS, and carnivorous species has become a significant challenge for evolutionary biologists to maintain ecological balance among other native species (Snoeks, 2001; Weyl et al., 2010). The present study revealed that the average yield of all carp fish, including exotic silver carp (*H. molitrix*) and grass carp (*C. idella*), was very low (2.83 kg.ha^{-1}), contributing only 1.56 % of total fish yield (Table 1). Ahmed et al. (2006) described that carp production gradually declined from 19 kg.ha^{-1} during the 1970s to 5 kg.ha^{-1} in the 1990s, while the yield of *C. soborna*, *G. manmina*, and *G. chapra* was 32 kg.ha^{-1} in 2001. This might be due to several reasons such as; the indiscriminate catch of carp brood fish, changes in water flow, siltation, destruction of feeding and breeding ground of carps, unregulated water-related tourism, sewage, incremental spillage of oil from boats and practice of brush fishery, which were also reported in Bashar et al. (2015) and Ahmed and Hambrey (1999). The brush fishery shelter is a fish aggregating device (FAD) to lure and concentrate fish in a certain area. The FAD consists of various types of floating objects such as logs, branches of trees and floating aquatic weeds, notably water hyacinth, *Eichhornia crassipes* (Mart. Solms-Laubach, 1883) and marsh herb, *Enhydra fluctuans* (Loureiro, 1790). This practice is now widely used in KL, although they are harmful and exploit any type of fish stock (Ahmed and Hambrey, 1999; Ahmed et al., 2006).

Cypriniformes was the most dominant order among the identified seventy-six fish species under ten orders, including seven exotic fish species. These findings are consistent with the previous research: total 84 fish species in the adjacent areas of the KL were reported by Basak et al. (2017), 6 exotic fish species out of total 74 fish species were reported in KL (IUCN Bangladesh, 2015a), and total of 86 species were reported by Ahmed et al. (2013) in the Chittagong hilly areas of Bangladesh. According to IUCN Bangladesh (2015), a total of twenty-one fish species were declared as threatened. Among the threatened fish species, 11, 8 and 2 were classified as vulnerable, endangered, and critically endangered, respectively. Others were accounted as near threatened (NT) (8) 11 %, data deficient (1) 1% and least concerned (LC) category, i.e., 39 (51 %). On the other hand, VU (5) 7 %, NT (6) 8 %, DD (4) 5 % and NE (4) 5 % while (57) 75 % were demarcated as least concern (LC) based on IUCN Global (2020) perspective (Fig. 5; Table 2). Threatened species reported from the present study were higher than in previous studies conducted by Haldar et al. (2003) and Chakma (2007). The higher number of threatened species might be due to heavy siltation, increased exploitation, brush fishery, habitat degradation, pollution, water level fluctuation, and climate change (Ahmed et al., 2006; Rahman et al., 2017). CR, EN, and VU species are either heavily exploited or under stress from habitat loss and several human-made and natural processes. In contrast, DD and NE species are not threatened yet (IUCN Bangladesh, 2015b). Among the total 25 exotic fish species available in Bangladesh, 7 species found in the KL have been introduced mainly for aquaculture in closed water bodies. Their escape into open water bodies posed a serious threat to the biodiversity of many aquatic organisms in Bangladesh (IUCN Bangladesh, 2015b). Such exotic fish species could threaten native fish by predation, competition for feed, habitat alteration, and the transfer of diseases (Sheath et al., 2015).

There are many causes behind the deterioration of water quality in KL and they are continuing. As a result, poor fish growth, sudden fish disease outbreak, algal bloom and poor production have become major concerns. Eight fish species have already become extinct from this lake, and the water quality deterioration was identified as one of the key reasons for these extinctions (Ahmed et al., 2006). There have been many illegal constructions of infrastructures surroundings KL and within the lake. These issues have also been raised in previous studies on KL (Ahmed et al., 2006; Rahman et al., 2014; Barua et al., 2016), in Chalan Beel (Rahman et al., 2010) and Halda River of Bangladesh (Karim et al., 2019; Moula et al., 2020). The introduction of seven exotic fish species and the surge of clupeids that are originally marine fish, have become one of the biggest challenges to the lake management authorities and fisheries biologists in Bangladesh. This is somewhat similar to the case in Lake Victoria in East Africa, where despite an increased fish yield, over 200 fish species were lost after introducing Nile perch, *Lates niloticus* (Linnaeus, 1758) (Ntiba et al., 2001). Kohinoor et al. (1998) observed adverse effects on the overall growth and yield of carp in polyculture with mola carplet (*A. mola*). Illegal, unreported, and unregulated fishing is another concern for the sustainable management of the fishery in this lake. Destructive fishing practices, including brush fishery, have created negative impacts on the feeding, breeding ground and natural propagation of fish in this lake (Fig. 7). Ahmed et al. (2006) also mentioned that similar threats were responsible for fish biodiversity decline in this lake. The rapid and uncontrolled proliferation of water hyacinth in the KL has seriously impacted negatively on the overall growth and yield of fish of KL, including hampered navigation and netting. Their rapid growth and proliferation in various freshwater, including lakes, streams, ponds, and ditches, negatively impact the overall growth and production loss of fish through ecological alteration (Patel, 2012).

Another global issue, climate change, is responsible for changes in fish migration paths, heavy siltation, severe attacks of diseases resulting in low fecundity and poor production from this important lake. Increased temperature with reduced rainfall resulting in mass siltation in Hamil Beel (Jahan, 2013), breeding problem, inferior growth with the frequency of diseases (Mollah, 2011), while lower water current with diminished fish production in Alua Beel (Rahman, 2013), Bangladesh was reported. A recent study predicted that about 35 % of the original species richness might decline in the Arabian Gulf by 2009 compared to 2010 due to climate change (Wabnitz et al., 2018). Surprisingly, climate change has tremendous effects on the rapid extension of water hyacinth (Patel, 2012), which has raised concern for the species richness of KL. All these factors have made a serious threat to the overall fish production and fish biodiversity of KL.

Management Overview and Recommendations

The main challenges for KL include managing wastewater or sewage discharge, other point source and non-point source pollution, development within the watershed (i.e., unplanned irrigation channel, dam, and road construction), and illegal fishing. KL was considered medium-productive and potential for improved fisheries (Ahmed et al., 2006; Bashar et al., 2015), while its production capacity was only 181.42 kg.ha^{-1} in 2018–2019 (Table 1). To facilitate natural propagation, annual fishing closures (90 days) occur during the peak breeding season. Six important nursery areas and breeding grounds have been created as sanctuaries, where fishing is banned (Fig. 1). However, illegal and unregulated fishing is widespread in remote areas of the lake.

Other laws have been enacted for fisheries conservation. For example, the minimum permissible mesh size for gill nets is 7.62 cm (3 inches), current jal (monofilament gill net) is strictly prohibited. Brush fishery is strictly banned to protect and conserve all types of fish, particularly brood fish. Illegal fishing and transportation are prohibited. Existing fisheries laws should be amended and strictly implemented to reduce illegal fishing at KL (Rahman, 2015).

For socio-economic development and to meet the demand for the animal protein of the surrounding communities of the KL, carp stocking has occurred since 1964. In 2018–2019, a total of 28 MT of fish were stocked (Fig. 8) with fingerlings supplied by a fish hatchery facility dedicated to stock enhancement in KL. Fish are usually stocked during the closed fishing period (from April–June annually). The following specific measures should be taken to minimise threats and improve the lake's management strategies and fish production. The effective regulations (e.g., catch-and-release), no-take zones in the breeding ground, and even relocation of habitat

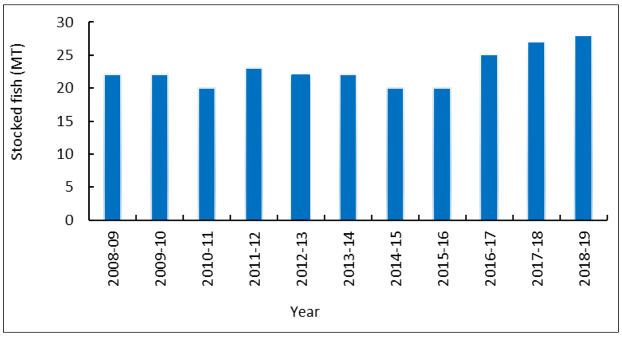

Fig. 8. Annual fish stocking trends during 2008-2009 to 2018-2019 in Kaptai Lake, Bangladesh.

should be enhanced (Cooke and Schramm, 2007). Community-based fish culture in creeks tributaries should be encouraged. For example, adequately managed creek aquaculture and cage culture should be initiated to utilise the lake resources efficiently. Carp polyculture in the creeks of KL, cage and pen culture demonstrated outgrowth performance (Bashar et al., 2014). Investigations to identify all potential natural breeding grounds of carp should be undertaken to increase the number of protected areas and restore habitats. There should also be an increase in annual stocking levels and improve stocked fish's size and condition. Lake dredging should be conducted only for emergency reasons, i.e., with proper plan and rapid implementation.

It is suggested that an adaptive management approach with strong collaboration among researchers, managers, government entities, power and water supply companies, and lake users (recreational and commercial fishers) to discuss and implement management strategies to address the issues.

Freshwater biodiversity conservation strategies are also recommended to boost when various sectors work jointly (Darwall et al., 2018). This will facilitate joint research and management opportunities to maximise the ecological and societal benefits of KL to the region. Raising public awareness through seminars, symposiums, science communication, and education (e.g., citizen science, participation in decision-making) is essential to sustainably manage the lake fishery (Cooke et al., 2013). Eco-friendly fish passage structures, irrigation channels and dams should be maintained (Steffensen et al., 2013).

Discharges of untreated sewage and industrial effluents into the natural water bodies have been a major concern for localised aquatic pollution. These result in fish kills and disappearances of fish from many freshwater bodies of Bangladesh (IUCN Bangladesh, 2015a, b; Sunny et al., 2020). KL fishery has been experiencing similar threats due to its water pollution. Pre-treatment or purification of polluted industrial water and municipal sewerage before their release into a natural water body is a national issue and should be made mandatory in the KL region due to the mass dependence on lake water for domestic purposes, sustainable fisheries management, aquatic biodiversity conservation as well as to avoid an unwanted and sudden rapid outbreak of fish diseases.

Conclusion

This study highlighted the fish production, threats, fish conservation status and associated management issues related to Kaptai Lake in Bangladesh. An increase in the number of threatened fish species, the reduction of many commercially important species, and the excessive yield of Ganges river gizzard shad, Indian river shad and Ganges river sprat are of great concern for researchers and management authorities. However, by implementing the recommendations that have been discussed in this study, the lake capacity with increasing fish production and biodiversity may be restored. Furthermore, wide-range research, collaborative management approach among government organisations, NGOs, fishers, local communities, and political leaders are essential to enrich Kaptai Lake fish productivity and biodiversity status.

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Conflict of interest: The authors declare that they have no conflict of interest.

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Appendix 1. Questionnaire.

Upazila: .... District: ....
Date ....

1. Name of Participant: -... Gender................
a) Place (at where interview taken): Lakeside/Residence/Market/Pontoon/Other
b) Occupation: - Fisherman/ Fish traders /Middleman/Retailer/Villager

2. Fishing operations: -
a) Gear ownership: -personal/rent/cooperative/employees/other..................................
b) Vessel ownership: - personal/rent/cooperative/employees/other...................................
c) Days fished in the last 15 days: -...
d) Fish species abundance: - very common/ common/ rare/ few ....
i) Type/name of fish caught today: - Catch by species ....Total catch (kg): ....
j) Which fishing area did you last fish: -...............................dd/mm/yy: ....

3. Personal overview about the lake fishery: -
Detail about climate change, pollution, encroachment, management etc. ....