A review of fish diversity, decline drivers, and management of the Tanguar Haor ecosystem: A globally recognized Ramsar site in Bangladesh

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HIGHLIGHTS
- Tanguar Haor (TH), a Ramsar site of economic and ecological importance, is home of 143 different fish species.
- The decline in fish diversity of TH is caused by a combination of climatic, anthropogenic, socioeconomic, and policy factors.
- Almost half of the people living in TH area were extremely poor and dependent on the haor for their livelihoods.
- Ecosystem-based co-management with active participation from the local communities is imperative for the conservation of TH.

ARTICLE INFO
Keywords: Fish diversity, Livelihood, Management, Ramsar site, Tanguar Haor, Ecosystems

ABSTRACT
Tanguar Haor (TH), an ecologically critical area (ECA) and a Ramsar site of worldwide significance, is an essential wetland ecosystem for the Bangladesh’s economic, ecological, social, and cultural aspects. Fish, aquatic plants, amphibians, reptiles, birds, and mammals are notable among the floral and faunal compositions found in this haor. Unfortunately, unsustainable exploitation of its natural resources poses a serious threat to the TH ecosystem. Therefore, the broad objective of this study was to review the status of fish biodiversity along with the driving factors of biodiversity loss and the management issues of the TH ecosystem. A total of 143 species of fishes (137 indigenous and 6 exotic) under 35 families, and 12 orders were documented during the last two decades. Species diversity of the haor has been changed over time due to the effects of climatic, anthropogenic, socioeconomic, and policy related drivers. Furthermore, high dependency on fisheries resources, poverty, and the lack of empowerment to manage the TH fishery were responsible for fish diversity decline. Therefore, ecosystem based co-management through active participation of local community, establishment of balanced fishing tactics, and strengthening alternative livelihoods for highly depended poor harvesters are strongly recommended for the proper management of this valued wetland ecosystem. Furthermore, this review proposes immediate and useful conservation initiatives for the studied wetlands, including comprehensive stock assessment, establishment of gene banks and fish sanctuaries, a combination of input and output control, and regulation with the ECA and RAMSAR guidelines.

1. Introduction
Bangladesh, a floodplain delta of the Brahmaputra, Ganges, and Meghna rivers, features one of the world’s wealthiest and most varied inland aquatic ecosystems, with a diverse fish fauna and vast water resources (Islam et al., 2015; IUCN Bangladesh, 2015a; Islam and Sultana, 2016; Mustafi et al., 2022). The nation is one of the world’s top fish producing countries, and during 2019–20 the total fish production was

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https://doi.org/10.1016/j.heliyon.2022.e11875
Received 28 June 2022; Received in revised form 3 August 2022; Accepted 17 November 2022
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4.5 million metric ton (MT) (DoF, 2020). Bangladesh has a total inland water area of 6.7 million hectares, with open water capture fisheries accounting for 94% and closed water aquaculture accounting for 6%, respectively (Hossain, 2014). According to the Food and Agriculture Organization (FAO) report, the nation was ranked third position in inland open water capture fisheries production (FAO, 2020). Inland fisheries, encompassing rivers and estuaries, forest water resources in the Sundarbans, beels, Kaptai Lake, floodplains, and haors, are mainly responsible for promoting the fish production of Bangladesh, with approximately 260 freshwater native fish species (DoF, 2020; Mustafi et al., 2022; Saha et al., 2021).

Typically, haor refers to a saucer-shaped marshy wetland habitats which are flooded for around 7–8 months, resembling a large inland sea during the rainy season (Pandit et al., 2022). The haor basin is a critical ecosystem for fish production both commercially and ecologically (Salauddin and Islam, 2011). It also serves as breeding, nursing, feeding, and overwintering habitats for residents and migratory fish species. For instance, about 154 native fish species covering 35 families and 12 orders inhabit in the haor wetlands (Pandit et al., 2022). In 2018–19, the total fish production of the haor region was 108,880 MT with a productivity of 433 kg/ha (DoF, 2019). Additionally, the growth rate of the fish production from the haor region was 12.11% between FY 2017–18 and FY 2018–19 (DoF, 2019). However, due to overexploitation, habitat fragmentation, silting of freshwater bodies, and environmental pollution from industries and agricultural chemicals, the percentage of inland capture fisheries to overall fish production had gradually decreased from 62.59% in 1983–84 to 28% in 2013–14 (DoF, 2019).

Bangladesh is an agriculture oriented nation with massive water resources (Sultana et al., 2016) in which Tanguar Haor (TH) is widely renowned freshwater wetland in the country (Figure 1). This haor extends across two upazilas (sub-districts) namely, Tahirkpur and Dharmapasha, in Sunamganj District, spanning more than 10,000 ha and serving at least 60,000 people (IUCN Bangladesh, 2016). The floral and faunal compositions in this wetland are renowned for their presence of various species of fishes, aquatic plants, amphibians, reptiles, birds, and mammals. TH is the home to approximately 141 freshwater fish species, and the richness of these fisheries is one of its unique features, paying it the title of ‘mother fishery’. TH’s fish stock was estimated to be 6701 tons (Ahmed, 2015) and this huge fisheries asset’s economic value estimated BDT 151,128,000 (USD 1 = 81 BDT) each year (Solayman et al., 2018). Moreover, this haor is crucial grazing, spawning, breeding, and nursing zone for different freshwater fish species. For this reason, it is referred to as the spawning, breeding, and nursing zone for different freshwater fisheries to overall fisheries production (FAO, 2020). Inland fisheries production both commercially and ecologically (Salauddin and Islam, 2011) plays an important role in the livelihood of TH region along with some recommendation measures. When it comes to the sustainable management of wetlands and inland waterbodies around the world, fisheries co-management has proven to be a successful tool. Over a decade ago, the co-management approach was alluded to in TH. This review also considers why the diversity of fish in TH declined. Furthermore, the review paper is a first attempt to find out the research gaps from previous works, recent biodiversity condition, and associated threats. The topics like current status, biodiversity value, and related threats have also been compiled that may be helpful for law and policy making organizations in determining future course actions for wise use and sustainable management of TH ecosystem of Bangladesh.

2. Methodology

Following the guidelines of Haddaway et al. (2015), we conducted a systematic review of the literature. We concentrated on peer-reviewed studies, PhD and Master’s theses, and scientific reports regarding TH that were written in English and published online (Figure 2). The data search was conducted in three comprehensive databases of scholarly publications- Web of Science, Google Scholar and Scopus between January and December 2021. We conducted a preliminary assessment of a subset of articles prior to the main search to determine the search-string combination to utilize. All results were evaluated for relevancy and to avoid papers that were not related to our focus for each search-string. Each string was tested individually. Examples of the search-strings include: water quality parameters, fish diversity, decline factors, management, conservation, livelihood profile and Tanguar Haor. Then, we found 87, 18, 16 peer reviewed papers from google scholar, web of science and scopus, respectively. Finally, we have reviewed 22 papers.

Relevant studies were identified by a step-by-step approach as shown in Figure 2 using EndNote X9. The step-by-step eligibility criteria were: All studies must include information on the author(s), year of publication and titles, duplicates were removed; article titles and abstracts were screened to include only studies conducted in TH; and the criteria for subsequent inclusion were that the articles, when fully read, considered water quality parameters, fish diversity, driving forces of biodiversity decline, socio-economic profile of engaged fishers, conservation and management strategies of the TH.

3. Results and discussion

3.1. Water quality parameters

Water is the most important component in shaping the land and regulating the climate, as well as provide life support system for all aquatic living organisms (Tasnim et al., 2022). Aquatic life is also impacted by the decline in water quality (Bhuyain et al., 2022; Tasnim et al., 2022). Water quality is affected by a wide range of physico-chemical and biological variables, which may have an immediate or passive impact on its quality (Moses, 1983). Within the standard...
limits, a slight decrease or rise in the concentration of dissolved or suspended materials has a negative impact on the body functions of aquatic organisms. During the monsoon the water quality in the TH area is regular, clean, and transparent. TH has a mesotrophic water quality (Bhuiyan et al., 2020). A few studies have been carried out to determine the different parameters (temperature, pH variation, total dissolved solid, dissolved oxygen, electrical conductivity, nutrient contents, and phytoplanktonic biomass) of the water of TH (Table 1). Based on analyses of different physicochemical and biological parameters, the TH is still devoid of high organic contamination, the water quality is relatively
good for fish production, and decline of fish has no direct association with water quality (Mamun et al., 2013; Bhuiyan et al., 2019).

3.1.1. Temperature

The water temperature of the TH varied from 22.4 °C to 31.0 °C with an annual mean around 26.0 °C (Bhuiyan et al., 2019, 2020). Solayman et al. (2018) determined the temperature ranged from 27.2 °C to 29.4 °C with a mean value of 28.2 °C from Rupaboi beel, Muinsakhali beel, Chatrar beel, Boddof beel, and Kolma beel of the haor. Similarly, Mamun et al. (2013) found 27.98 °C as the mean value of water temperature and recorded the minimum value 27.8 °C and the maximum value 28.1 °C.

3.1.2. pH variation

The water pH value of the haor normally fluctuates between 8.1 and 9.7 from December to March and 7.5–7.7 from April to September (Bhuiyan et al., 2020). However, the study of Bhuiyan et al. (2019) recorded the pH values range between 7.2 and 9.7 in the Rauar area of TH throughout the year. Solayman et al. (2018) found the average pH value ranges from 8.1 to 9.7, while Mamun et al. (2013) reported that the average value spans from 6.9 to 7.6. However, the average water pH value in TH is suitable for survival of fish as the pH value 6.5 to 8.5 is considered normal for fisheries (ECR, 1997).

3.1.3. Dissolved oxygen (DO)

Solayman et al. (2018) recorded the average DO content ranged from 4.27 mg/l to 8.56 mg/l. Mamun et al. (2013) discovered 5.5 mg/l as the peak DO value, 4.5 mg/l as the lowest DO value, and 5.02 mg/l as the mean DO value. Surface water with a DO value of 5 mg/l or higher is favorable for fisheries (ECR, 1997) which supports the diversified fisheries of TH.

3.1.4. Total dissolved solid (TDS)

Compared to other waterbodies in Bangladesh, TH has a relatively low TDS (mean = 63.5 mg/l). The TDS value ranges from 51 to 85 mg/l in Rauar area and from 58 to 77 mg/l in watch tower area of TH throughout the year (Bhuiyan et al., 2019, 2020). However, Mamun et al. (2013) and Solayman et al. (2018) found the ranges from 731 to 1020 mg/l and 670–1036 mg/l, respectively. The authors of both pieces of research opined that the higher TDS value of water may be ascribed to the high dissolved ion content of upstream water and domestic contaminants (Mamun et al., 2013; Solayman et al., 2018).

3.1.5. Electrical conductivity

Bhuiyan et al. (2020) measured and recorded the mean electrical conductivity of TH water at 80.75 μS/cm. However, the conductivity value

### Table 1. Water quality parameters of the Tanguar Haor.

| Parameter                          | Mamun et al. (2013) | Bhuiyan et al. (2019) | Bhuiyan et al. (2020) |
|-----------------------------------|---------------------|-----------------------|-----------------------|
| Temperature (°C)                  | Min. 27.8 Max. 28.1 Avg. 28 | Min. 22.4 Max. 31.0 Avg. 26.33 | Min. 22.7 Max. 30.3 Avg. 26.52 |
| pH                                | Min. 6.9 Max. 7.6 Avg. 7.32 | Min. 7.2 Max. 9.7 Avg. 8.3 | Min. 7.5 Max. 9.7 Avg. 8.33 |
| Dissolved oxygen (mg/l)           | Min. 4.5 Max. 5.5 Avg. 5.02 | Min. 2.44 Max. 6.09 Avg. 3.77 | Min. 2.5 Max. 6.09 Avg. 3.97 |
| Total dissolved solid (mg/l)      | Min. 670 Max. 1036 Avg. 846 | Min. 51 Max. 85 Avg. 64.17 | Min. 51 Max. 79 Avg. 62.83 |
| Electrical conductivity (μS/cm)   | Min. 1044 Max. 1658 Avg. 1294 | Min. 60 Max. 110 Avg. 81.67 | Min. 67 Max. 100 Avg. 79.83 |
| Secchi disk depth (m)             | Min. - Max. - Avg. 2.08 | Min. 2.08 Max. 3.05 Avg. 2.48 | Min. 2.08 Max. 3.05 Avg. 2.54 |
| Soluble reactive phosphorus (μg/l)| Min. - Max. - Avg. 5.43 | Min. 5.43 Max. 36.43 Avg. 16.30 | Min. 9.76 Max. 30.05 Avg. 18.07 |
| Soluble reactive silicate (mg/l)  | Min. - Max. - Avg. 4.00 | Min. 4.00 Max. 14.58 Avg. 9.55 | Min. 4.45 Max. 16.14 Avg. 9.92 |
| NO₃–N (mg/l)                      | Min. - Max. - Avg. 0.06 | Min. 0.06 Max. 0.31 Avg. 0.18 | Min. 0.25 Max. 0.75 Avg. 0.43 |
| NH₄⁺ (μg/l)                       | Min. - Max. - Avg. 550 | Min. 550 Max. 1230 Avg. 813 | Min. 690 Max. 1380 Avg. 840 |
fluctuates from 60 to 110 μS/cm throughout the year (Bhuiyan et al., 2019). On the other hand, the study from Mamun et al. (2013) and Solayman et al. (2018) have found that electrical conductivity ranges from 1044 to 1658 μS/cm with the average value of 1294.4 μS/cm and 1120 to 1460 μS/cm with the average value of 1231 μS/cm, respectively. According to Bhuiyan et al. (2019), the transparency value found in the TH (Secchi depth 2.48 m) is very compatible with the TDS, conductivity, DO, SRP, and chl-a values measured. Bhuiyan et al. (2019) also compared the TDS and conductivity values with the values measured in other waterbodies of Bangladesh (Khillikhet Bed, Joysagar, and Hakaluki Haor) and found that the values were consistent with each other. The consistency of the recorded TDS and conductivity values of TH by Mamun et al. (2013) and Solayman et al. (2018) with the values found in other waterbodies.

3.1.6. Water transparency

The Secchi disc depth is a limnological measure that has been incorporated in European legislation as one of the main criteria in assessing water quality (Dominguez Gómez et al., 2009). With a Secchi disk depth of 2.48 m on average, the water transparency of TH remained reasonably steady (2.08–3.0 m) throughout the year (Bhuiyan et al., 2019, 2020). The fairly low Secchi depth findings depicted that the haor is devoid of biotic and abiotic dissolved materials.

3.1.7. Nutrient content

The nutrient profile analysis is an important part to think about the productivity of any waterbody, although the TH was found to be deficient in nutrients. Different studies have found that the soluble reactive phosphorus (SRP) levels, soluble reactive silicate (SRS) levels, NO₃–N levels and NH₄ levels were ranges from 9.76 to 30.05 μg/l, 4.45–16.14 mg/l, 0.25–0.48 mg/l and 270–1380 μg/l, respectively, at the watch tower area of the haor (Bhuiyan et al., 2020). However, the highest concentrations of SRP (30.05 μg/l) SRS (16.14 mg/l), and NH₄ (1380 μg/l) were observed in September, March, and April, respectively (Bhuiyan et al., 2020). In the Rauar area of TH, SRP, SRS, NO₃–N, and NH₄ concentrations ranged from 5.43 to 36.43 μg/l, 4–14.58 mg/l, 0.06–0.31 mg/l, and 238–1230 μg/l, respectively (Bhuiyan et al., 2019). Highest amounts of NH₄ (905 and 1230 μg/l) was found during winter season. According to Bhuiyan et al. (2019), the highest concentration of NH₄ in winter season could be due to a presence of higher population of migratory birds during that time. The Watch Tower area has a higher concentration of vital nutrients, such as SRP, NO₃–N, SRS, and NH₄, than the Rauar area (Bhuiyan et al., 2020).

3.1.8. Phytoplanktonic biomass

Phytoplanktonic biomass (Chl-a) concentrations ranged from 1.35 to 8.45 μg/l, while its degradation product pheophytin concentrations ranged from 0.08 to 3.5 μg/l in TH was recorded by Bhuiyan et al. (2019). A low chl-a value indicates a low phytoplankton standing crop as because of the low concentrations of SRP, SRS, and TDS, occurs (Bhuiyan et al., 2019). Lower phytoplankton biomass in TH might have led in low DO and conductivity.

3.2. Fish biodiversity

In the TH, 143 species of fish (137 indigenous and 6 exotic) belonging 35 families, and 12 orders were documented by several studies (Hossain et al., 2012; Alam et al., 2015; Sunny et al., 2020; Hussain, 2021). Status of indigenous species is presented in Table 2. Highest numbers (%) of species came from Cypriniformes order, followed by Siluriformes, Anabantiformes, and Perciformes (Figure 3). Mohan et al. (2020) found 39 species belonging to 9 orders and 19 families from the East Kolkata Wetlands the only Ramsar site in the State of West Bengal, India. Cutler et al. (2019) sampled 31 sites within and around the Rapids of Mboongou Badouma and Doume Ramsar site and collected 97 species in 18 families and 9 orders. Karadeniz (2000) surveyed Sultan Sazligi Ramsar site in Turkey and recorded 25 species of mammals, 25 species of mollusks, 5 species of fish, 301 species of birds, and 125 species of algae. Lakshmi et al. (2015) found 78 fish species belong to 14 orders, 37 families and 57 genera from Kolluru Lake of Andhra Pradesh, India. Fahmi-Ahmad et al. (2015) recorded a total of 52 species belonging to 20 families of freshwater fishes from Tasek Bera Ramsar Site, Peninsular Malaysia. Comparing with the above mentioned Ramsar sites around the world, the TH wetland supports higher number of fish species.

From the last two decades, fish species recorded in different years from TH showed decline in species diversity although these decline in fish diversity are likely due to differences in survey season, method of sampling, number of sites and effort, etc. As, Hossain et al. (2012) recorded 120 indigenous fish species; Alam et al. (2015) found 128 indigenous fish species; Sunny et al. (2020) recorded 75 indigenous fish species and Hussain (2021) found only 56 indigenous species of fish (Figure 4). Sun et al. (2017) studied both Poyang Lake wetland in China and Tanguar Haor wetland in Bangladesh and found that both wetlands have shown a decline in the fish population, with the Tanguar Haor wetland experiencing a bigger decline.

Table 2. Status of available indigenous fish species in the Tanguar Haor (Hossain et al., 2012; Alam et al., 2015; Sunny et al., 2020; Hussain, 2021).

| Sl no. | Order                  | No. of families | No. of species | IUCN status in Bangladesh | Global IUCN status |
|--------|------------------------|----------------|---------------|---------------------------|-------------------|
|        |                        |                |               | CR | EN | VU | NT | LC | DD |        |        |        | CR | EN | VU | NT | LC | DD | NE |
| 1      | Anabantiformes         | 5              | 14            | 1  | 1  | -  | 2  | 10 | -  | 1  | 1  | 11 | 1    | 1   |     |     |     |     |     |     |
| 2      | Beloniformes           | 2              | 2             | -  | -  | -  | -  | 2  | -  | -  | -  | 2   | -    | -    |     |     |     |     |     |     |
| 3      | Clupeiformes           | 2              | 5             | -  | -  | 2  | -  | 2  | 1  | -  | -  | 5   | -    | -    |     |     |     |     |     |     |
| 4      | Cypriniformes          | 6              | 57            | 4  | 10 | 5  | 12 | 22 | 4  | 1  | 3  | 51 | 1     | 1   |     |     |     |     |     |     |
| 5      | Cyprinodontiformes     | 1              | 1             | -  | -  | -  | -  | 1  | -  | -  | -  | 1   | -    | -    |     |     |     |     |     |     |
| 6      | Mugiliformes           | 1              | 2             | -  | -  | 1  | -  | 1  | -  | -  | -  | 2   | -    | -    |     |     |     |     |     |     |
| 7      | Perciformes            | 3              | 7             | -  | -  | 2  | 5  | -  | 1  | 4  | 1  | 1    | 1     | 1    |     |     |     |     |     |     |
| 8      | Siluriformes           | 10             | 39            | 3  | 7  | 4  | 5  | 17 | 3  | 1  | 6  | 30 | 2     |      | 1    |     |     |     |     |     |     |
| 9      | Synbranchiformes       | 2              | 5             | -  | 1  | 2  | 1  | 1  | -  | 5   | -    | -    | -    |     |     |     |     |     |     |
| 10     | Syngnathiformes        | 1              | 2             | -  | -  | 2  | -  | -  | -  | -  | -  | 1   | -    | -    |     |     |     |     |     |     |
| 11     | Tetraodontiformes      | 1              | 1             | -  | -  | -  | -  | 1  | -  | -  | -  | 1   | -    | -    |     |     |     |     |     |     |
| 12     | Ostegocephaliformes    | 1              | 2             | -  | 1  | 1  | -  | -  | -  | -  | -  | 1   | -    | -    |     |     |     |     |     |     |
| Total  |                        | 35             | 137           | 8  | 20 | 17 | 22 | 62 | 8  | 3  | 13 | 114 | 5     | 2    |     |     |     |     |     |     |

Status Code: CR- Critically Endangered, EN- Endangered, VU- Vulnerable, NT- Near Threatened, LC- Least Concern, DD- Data Deficient, NE- Not Evaluated.
3.3. Drivers of fish diversity decline

TH supports a remarkable array of diversified fish fauna, but these are now facing severe threats because of a combination of different climatic, anthropogenic, socioeconomic, and policy related drivers.

3.3.1. Climatic drivers

3.3.1.1. Erratic rainfall. Erratic rainfall was discovered to be a primary climatic component that was linked to a reduction in fish species diversity in the TH (Rahaman et al., 2016; Sunny et al., 2020). After winter, depending on the rainfall the brood fish migration from deeper water to the breeding ground typically occurs between February and March. Between May and October, TH receives more than 80% of its annual total rainfall (Rahaman et al., 2016). Due to unpredictable rainfall from the end of February to the first week of March, there is insufficient water supply in the rivers and beels of the haor; yet, this immediately encourages fish breeding, especially small indigenous fish species. When there isn’t enough rain, certain fish took part breeding, but their larvae don’t grow because of the scarcity of water (Aziz et al., 2021). Furthermore, the brood fish cannot reach the breeding grounds of the haor in time due to rainfall fluctuation (shortage of rainfall/late rain fall etc.) and shortage of water in the associated rivers and canals (Akintola, 1995). As a result, climate vulnerability due to unpredictable rainfall has impacted on fish breeding activity and diversity compared to a few decades earlier (Chowdhury et al., 2010).

3.3.1.2. Temperature fluctuation. Temperature fluctuations are another important element that influences physiological and ecological processes, which can lead to a decrease in the richness and distribution of fish species in a body of water (Islam et al., 2016; Bhuyain et al., 2022). Temperature has a profound influence on all physiological processes, especially reproductive activities including gamete formation, ovulation and spermiation, spawning, embryogenesis, and hatching, as well as larval and juvenile development and survival, which are all linked to fish species diversity. Temperature changes, a fundamental climatic phenomenon, change the physico-chemical characteristics of aquatic ecosystems and plankton productivity, resulting disturbance in fish migration and distribution, which has an indirect but detrimental impact on fish abundance (Chowdhury et al., 2010; Islam et al., 2015). Evaporation from open water and evapotranspiration from vegetated surfaces are both affected (Rahaman et al., 2016).

3.3.1.3. Siltation. Siltation in the beels had a great impact on haor fishery’s reduction. It results in the degradation of the fish’s natural habitat. Land-use changes in the upper riparian zone may enhance haor sedimentation and disrupt the Jadukata-Patlai River ecosystem (Alam et al., 2015). Flashflood from the upper hilly region of India causes severe siltation in the haor wetland. Due to siltation fish species diversity usually harmed by collapsing the fish migration pathways and the disappearance of small beels that was served as feeding grounds (Islam et al., 2018; Khan, 2011). Furthermore, fish larvae’s feeding grounds and migratory routes are restricted due to siltation at haors-river junction places. The water regimes of various aquatic environments, such as beels, rivers, and...
canals, vary seasonally. Sediment intrusion from upper hill deforestation and its deposition in beels has been observed to diminish light permeability and dissolved oxygen in the water, resulting in lower egg, embryo, and post-larvae survival (Chapman, 1988). Increased turbidity in waterbodies reduces light penetration, which can affect primary productivity, as well as the diversity of fish feeding organisms (secondary production), and eventually, fish species diversity (Islam et al., 2015; Barman et al., 2021).

3.3.2. Anthropogenic drivers

3.3.2.1. Use of harmful fishing gears. The most major anthropogenic factor contributing to the decrease of fish species diversity in the TH is the direct use of harmful and illegal fishing gears. Use of synthetic monofilament gill nets (current jal), fine-meshed seine nets (ber jal), and other illegal fishing devices has become a major worry in the haor in recent years (Alam et al., 2015). Tima et al. (2021) found destructive and prohibited fishing gears such as current jal and fine meshed ber jal used for catching undersized fishes. Anglers can easily catch fish eggs and fry with these fishing gadgets. During FGDs fishermen reported that they putting traps for small fish along their migration route which allowing the fishermen to readily capture fish fry and eggs. Similarly, the broodfish swim close to the haor’s bank at night and are captured by anglers using harpoons (dragging gear). Fish and other aquatic species are exposed to exploitation when those damaging fishing gears and other methods (for example, fishing by de-watering, using chemicals) are used, and the regulatory authority (DoF) has declared these as illegal fishing operations (Rahaman et al., 2016). However, in the absence of adequate government oversight, fishermen in haor regions continue to employ dangerous fishing gear and practices as a result, the diversity of fish species has decreased (Sultana et al., 2016). The Department of Fisheries has also set limitations on catching brood fish and juveniles from natural sources in order to protect fish species and their habitats. However, due to a lack of regulatory capability, no noticeable impacts on fish conservation were recorded (Khan, 2011).

3.3.2.2. Development of infrastructures. Establishment of crop dams around this haor is disrupting the water flow and fish movement that may affect natural recruitment and dispersal pattern of this mother fishery (Alam et al. 2015). Construction of road, bridge, culvert, etc. is also disrupting the migratory routes and affected natural recruitment (Barman et al., 2021).

3.3.2.3. Over and indiscriminate fishing. Another anthropogenic activity that has diminished fish species diversity in the haor is overfishing. Overfishing destroys thousands of species at risk which is ultimately responsible for the food and nutrition security of hundreds of millions of people around the world (Golden et al., 2016; Koning et al., 2020). Capture fishing and agriculture are the two main sources of income for the residents in the haor. Because of the reduction of wetlands, more than 40% of freshwater fish species are now classified as threatened with extinction at the national level (IUCN, 2003). TH is in danger of losing practically all fish species due to overfishing, which is a severe threat to fish stocks in the haor (Rahaman et al., 2016). Indiscriminate fishing during the breeding season, as well as a reluctance to follow the sustainable fish harvesting method created under the CBMTH project, were noticed as serious risks to the conservation of fish species in TH (Alam et al., 2015). Overfishing, fishing during ban period, catching undersized fish, fishing at the restricted areas (sanctuary area), and fishing during spawning seasons were recorded by Tima et al. (2021).

3.3.2.4. Water pollution. Water contamination, which is occasionally caused by coal storage and transportation at Tekerghat point in the TH, is another threat to floral and faunal species. Thousands of boats continuously pollute the water through oil spill and destructive fishing gears which is ultimately affecting the fish population (Alam et al., 2015). Due to aquatic pollution, certain fish species that were available in the TH have now very rare or extinct (Tima et al., 2021).

3.3.2.5. Degradation of swamp forest. The amount of fish produced by TH is clearly diminishing day by day due to the destruction of swamp forest, and the number of other fish species has also decreased significantly. Swamp forests that were once abundant in TH have become extremely rare as a result of removal, cutting, and other anthropogenic pressures, however remnants still exist. The natural regeneration of this forest type is barely noticeable in the marsh, except along the bank of the Foilier beel. The reed beds have also been badly depleted as a result of ongoing overharvesting for fuel and land conversion to agricultural fields. As a result, certain aquatic species that were once prevalent in the area have become extinct and the integrity of the haor ecosystem was jeopardized due to this process (GoB, 2004). Because swamp forest provides food and shelter for fish, there has been a decline in fish production, species variety, and waterfowl populations during the last few decades (Alam et al., 2015; Islam et al., 2016).

3.3.3. Policy related drivers

Fish biodiversity status may be disrupted after the termination of the existing management system because community motivation and system involvement are absent, and insufficient policy frameworks and legislative provisions for biodiversity conservation and protected wetland management (Alam et al., 2015). Tima et al. (2021) found several causes of degradation of fisheries resources of TH as weak enforcement with inadequate surveillance and poor implementation of the legal framework, non-compliance with fishing laws, rules, and policies.

Similar types of drivers were found in other freshwater wetlands in Bangladesh and around the world (Sun et al., 2017; Husen et al., 2019; Aziz et al., 2021; Amoutchi et al., 2021). Erratic rainfall, temperature and siltation have become a significant climatic component that positively correlates with a decrease in the variety of fish species in the Hakaluki Haor, having a considerable impact on fish harvest (Aziz et al., 2021). Amoutchi et al. (2021) observed Ivorian freshwater fish abundance reduction as a consequence of climate change especially change in temperature and rainfall and several anthropogenic activities including gold mining, water withdrawal for human needs, use of small-mesh fishing nets, overfishing, industrial waste discharge, pesticides use for agricultural purposes, obnoxious fishing practices and increase in human population. According to Cooke et al. (2012), riparian and floodplain habitat degradation, altered hydrology, migration barriers, fisheries exploitation, environmental (climate) change, and introduction of invasive species have made riverine fishes some of the most threatened taxa on the planet. Hydrological alterations were found as the largest threat to fish biodiversity in the Yangtze River basin of China by Fu et al. (2003). Moyle and Leidy (1992) identified proximate causes of fish species’ decline of aquatic ecosystems and divided them into five categories as competition for water, habitat alteration, pollution, introduction of exotic species, and commercial exploitation. Sinha and Khan (2001) recorded major causes of fish decline in the Ganges River and found discharge of wastes generated due to developmental activities including irrigation projects, river course modifications and demographic explosion in the basin, which destroyed floodplains, sloughs, inundation zones, and oxbow lakes. Besides, the hydraulic structures have destroyed the anadromous fishery (Tenualosa ilisha, Pangasius pangasius) of the riverine stretch of the Ganga. Rahaman et al. (2019) recorded climate change as the main driving factor of fish diversity reduction in Meghna River. The overfishing, area application, annual beel drying, and usage of damaging fishing gears created a clear picture of the anthropogenic factors involved for the decline in fish species diversity in Hakaluki Haor (Aziz et al., 2021). However, overfishing, use of illegal fishing gears (current jal), katha fishing, fishing by dewatering, low water depth in winter, abstraction of water for irrigation, siltation, catching of fry and...
brood fishes were found as major fish diversity decline factors in different wetlands of Bangladesh (Sultana et al., 2019; Barman et al., 2021; Das et al., 2022; Kamal et al., 2022). The lakes in Pokhara Valley in Nepal were mostly affected by illegal fishing practices, siltation and sedimentation, water pollution, fish habitat loss, increased eutrophication, biological invasion, intensification of agriculture, and development projects (Husen et al., 2019). These drivers have changed the lake’s size, water quality, depth, and availability of natural food, which has had an impact on aquaculture and fisheries in the lake (Husen et al., 2019).

According to Cutler et al. (2019), freshwater ecosystems face considerable threats that fall into four major categories such as over-exploitation, introduced species, habitat destruction, and pollution. The authors added most visible threat to biodiversity of Mbangou Badouma and Doume Ramsar sites of this region is habitat destruction and pollution associated with mining, dams, and timber extraction (Cutler et al., 2019). Kumar et al. (2018) found anthropogenic pressure arising out of alterations of wetland habitats to agricultural lands, habitat destruction, over exploitation, wanton destruction, aquatic pollution, disease, exotic species introduction and overall lack of awareness of biodiversity importance, and absence of proper policy are contributing much to such alarming vulnerability of the rich fish diversity of the East Kolkata Wetlands. Siwakoti and Karki (2009) described various kinds of threats from different Ramsar sites of Nepal and grouped as 1) Destruction and degradation of wetland habitats which includes high rate of drainage and reclamation of wetlands for housing, urban and industrial uses, inappropriate wetland management due to high water pumped for dry season crop, fish harvesting, modification of land use for agriculture; and fragmentation due to encroachment, 2) Loss of wetland ecosystem integrity includes construction of dams, barrage, etc. for hydropower, irrigation and flood management, over-expansion of ground water for domestic and other water requirements, increasing pollution by the use of high doses of pesticides/herbicides and fertilizers in the surrounding agricultural land, industrial waste and domestic sewage; and sedimentation and 3) Depletion of species abundance and diversity includes over harvesting of bio-resources (fishing, grazing, poaching, etc.), destructive harvesting practices (fish bombing, electro-fishing, poisoning, draining, use of small mesh nets, etc.); introduction of invasive alien species of plants which supports the present threats found as responsible for biodiversity depletion of TH.

3.4. Socio-economic profile of the haor inhabitants

3.4.1. Livelihood profile

TH provides versatile opportunities of livelihood for a number of needy people, many of them living under the poverty level, in the form of fishers, farmers, fish traders, transporters, intermediaries, day laborers, etc. More than 70 thousand people in 46 villages around the TH rely on this wetland for their livelihoods, either directly or indirectly (Sun et al., 2017). According to Islam et al. (2014), nearly half of the inhabitants in the TH region are extremely poor, while the IUCN et al. (2008) survey found that 95 percent of the people in the region struggle for living and 81% rely on the TH for their income.

Fishing practice mainly increases during the monsoon, but most of them engage with agricultural practices in the dry season. Primarily, fishing (30.1%) is the main occupation in TH followed by agricultural farming (12.9%), rearing livestock (8.6%) and businessman (8.6%) were found as the professions which is varied with landmass distribution and season (Table 5). The percentages of fishing profession decrease with the increasing distance from TH (Islam et al., 2014).

3.4.2. Age distribution and farm size

In TH, people of almost all ages are engaged in fishing or other earning activities for supporting their livelihoods. Different researchers have classified them on the basis of age in different ways. However, the majority of middle-aged people are usually observed here in fishing activities. Mamun et al. (2013) found that 45.5% fishers are 31–42 years, 5.5% are under 30 years age and 24.5% fishers are more than 54 years old but Uddin et al. (2015) reported that age of respondents ranged from 19 to 75 years (average 47.6 years). Most of them (42%) were belongs to the old aged group (Table 4). As we found, most of the people in the TH are very needy and living below the poverty level. Most of them are landless or having few land area with an average of 0.4 ha farm size (Table 4) and 50% of them are small farmer while only 4% are large farmer (Uddin et al., 2015).

3.4.3. Education rate and family size

The distant and time-consuming transportation system, insufficient educational institution, adverse weather condition during dry and monsoon period and poor income of household head has made the low educational rate in this area. About 29%–42% of the population had only an elementary education, while 36%–39.8% were illiterate (Table 5). The literacy rate was determined to be lower than the national average of 74.70% (BBS, 2020). A big family has more people to extract natural resources from TH than a small family. That’s why there is a trend in rural community people of TH area having more children. So that after few years of growing the children can contributes to the family income through extraction of natural resources. More than half of the respondents (54%) had a medium-sized family, compared to 22% who had a small family and 24% who had a large family.

The average household size in Bangladesh is 4.7 (BBS, 2020), but it is approximately 6 in TH, which is higher than the national average and this is happened as the people are conservative by nature and yet have a primitive view on family planning (IUCN et al., 2008; Islam et al., 2014; Uddin et al., 2015).

3.4.4. Income and expenditure

Most of the people in TH are hardcore poor and directly or indirectly depend on the TH which is significantly influenced by the season, climatic condition, natural disaster and price fluctuation of their products such as fish, cattle, and agricultural field crops (Uddin et al., 2015). In 2008, the mean annual income of a household in TH was 22,642.44 ± 594.52 BDT. 38,059 BDT. In 2012, the majority of respondents were impoverished (40%) while only 12% were prosperous and 10% were extremely poor (Table 6). However, until 2012, the majority of haor

| Variables | Percentages (%) | References |
|-----------|-----------------|------------|
| 1. Fishers | 38.9 | Uddin et al. (2015) |
| 2. Farmer | 33.7 | Uddin et al. (2015) |
| 3. Livestock rearing | 3.2 | Uddin et al. (2015) |
| 4. Day labor | 2.1 | Uddin et al. (2015) |
| 5. Traders | 8.4 | Uddin et al. (2015) |
| 6. Service | 3.2 | Uddin et al. (2015) |
| 7. Boatman | 5.3 | Uddin et al. (2015) |
| 8. Netters | 0.24 | Uddin et al. (2015) |

Table 3. Leading occupations of the people in the Tanguar Haor region.
residents were surviving on less than 5000 taka per month. More crucially, about 30% of the households earned between Tk. 1500 and Tk. 3000 per month, while 39% earned between Tk. 3000 and Tk. 5000 per month. Only 2.57% had a monthly income of more than Tk.10000, and 39% earned between Tk. 3000 and Tk. 5000 per month. However, these sources became vulnerable due to over exploitation and extraction over time. In this area only few households had brick walls. Around 21.4% of the people in TH area live in a single room house. The majority of the houses now tin roofs instead of reeds. Bamboo and tin made wall is the most common feature of the households in villages surrounding the TH (Uddin et al., 2008).

3.4.5. Households area and house materials

In rural Bangladesh, almost 28.6% of the families exist underneath the lower poverty line and almost 43.8% of the families live beneath the upper poverty line (BBS, 2020). In Tanguar villages, 2.8% families have no matured male individuals for earning, 13.89% families have no income creating resources, 31% of the families have a land area lower than 10 decimals and almost 49% families have less than 50 decimals of land area (IUCN et al., 2008; Table 8).

Living in TH area is very difficult because it is one of the remotest areas of Bangladesh. Because of its poor communication infrastructure and vulnerable economic condition of the people limited their access to the major cities. That’s why most of the materials required for building houses in Tanguar area are usually come from the TH itself. Swamp forest supplies structural materials and reeds used for the roofing materials.

Table 5. Education rate and family size of local people in Tanguar Haor (Islam et al., 2014; Uddin et al., 2015).

| Education rate | Type | Percentage (%) | Family size | Types | Percentage (%) |
|----------------|------|----------------|-------------|-------|----------------|
| Illiterate     | 36–39.8 | Small (<5) | 22          | Small (<5) | 22          |
| Primary        | 29–42 | Medium (5–8) | 54          | Medium (5–8) | 54          |
| Secondary      | 18–26.9 | Large (>8) | 24          | Large (>8) | 24          |
| Above Secondary| 4–4.3 |              |             |              |              |

Table 6. Changing pattern of monthly income of the respondents in Tanguar Haor (Uddin et al., 2015).

| Income Group  | Level of Income (BDT) | Respondents (%) | Change (%) |
|---------------|-----------------------|-----------------|------------|
| Extreme poor  | <1999                 | 18              | 44.4       |
| Poor          | 2000–4999             | 48              | -16.7      |
| Medium        | 5000–7999             | 26              | +46.2      |
| Rich          | >8000                 | 8               | +50.0      |

3.4.6. Sanitation status, source of drinking water and fuel

Sanitation is a main problem in Tanguar villages. There are mainly three types of latrine. These are sanitary brick built latrines, latrine with only ring slab and open latrines are made on a shaft and hanging is made by 4–8 bamboos, fenced by plastic sheet which is hanged on the haor, river or nearby canal (Islam et al., 2014). Only 7.5–11.6% of the population has access to toilets. Another 12.8%–21.5% use ring-slab or semi-building latrines, while the remaining 71.6–77% use bamboo-made, semi-open, or open latrines to defecate straight into local rivers, canals, and creeks (Islam et al., 2014). Like as the other wetland areas, safe drinking water facility is a more common problem in the haor area as like the other large wetland areas of Bangladesh (IUCN et al., 2008). Though TH is a major waterbody and a Ramsar site, but residents
in the area lack access to safe drinking water. Only 74.2–88.3% people have access to shallow tube-well in TH whereas the national average is 97% (Islam et al., 2014). There is only 1–2 shallow tube well in a village for approximately 600–800 people and it is very hard to collect drinking water in different times like in rainy season or at night. On the other hand, few people like financially well-established set up deep tube-well only for their own family. For the difficulty in access in shallow tube-well around 17.2% people used to drink river or haor water. In the past people of different regions of Bangladesh, using water from ponds, canals, and rivers for household chores was common practices, but in TH, over 77.6% of people still do! (IUCN et al., 2008; Islam et al., 2014). As there is no alternative way for cooking food except fuel wood about 50% people of TH used to collect grasses, and 30.1% collect leaves, branches of trees from the swamp forest. Rest of the people use dried cow dung (19.4%) as their daily fuel wood. Use of cow dung as a fuel has a considerable negative impact on the environment (IUCN et al., 2008; Islam et al., 2014).

3.4.7. Income determinants of the fishermen in haor region

The income of the fishermen can be affected by several factors, such as the fish catch, age of fishermen, and training program provided in the area (Ahmed et al., 2021). To analyze these factors, Tikadar et al. (2022) carried out a multiple linear regression model in haor area and a summary of that finding is presented in Table 9. The results show that age of the fishermen, education rate, training program and NGO membership of the fishermen influence their income positively and significantly. Older fishermen tend to have greater experience than the younger. They catch more fish because they are well-versed in the ecology of the floodplains. Additionally, they have better market knowledge, which helps them negotiate a higher price for the fish.

3.5. Current management status of Tanguar Haor

In Bangladesh, the Protection and Conservation of Fish Act, 1950, is regarded as the founding document for fisheries management. The purpose of this act was to control the use of current net, fixed engines, explosives, and other dangerous fishing methods by all species in all natural or manmade, open or closed, flowing or stagnant, bodies of water. The Protection and Conservation of Fish Act, 1950 underwent a number of amendments (Tima et al., 2021). Given the economic and ecological significance of the TH natural resources, it demands for key attention of policy makers for the sustainable resource management. Therefore, two major conservation initiatives, namely, the ‘National Conservation Strategy (NCS)’ and the ‘National Environmental Management Action Plan (NEMP)’ were accomplished by the government of Bangladesh to formulate different management plans for the biologically rich ecosystems in 1990 (Bevanger et al., 2001). In addition, the ‘National Conservation Strategy Implementation Project-1 (NCSIP-1)’ has been started under the NCS, in which the TH wetland ecosystem was one of the most important parts of this project. Then a ‘Tanguar Haor Management Plan (THMP)’ was developed in February 2000, which was also signed by the Ministry of Finance of the Royal Norway for financing this project in 2001 (Bevanger et al., 2001).

About two decades later of NCS, one more intensive field-based survey was conducted in the TH during 2012–2014. It was done by another project named the ‘Community Based Sustainable Management of TH (CBSMTH)’, especially to make out the fish resources status of the TH and its adjacent beels (Alam et al., 2015). Since the fish sanctuaries serves as an integral part of the conservation process (Kunda et al., 2022), five distinct fish sanctuaries were constructed in this haor under the CBSMTH project in 2011 (Ahmed, 2013; Alam et al., 2015). Among them, four sanctuaries were established in four distinct beels, and one more fish sanctuary was recognized in the Patlai River’s Alamer Duar. However, Table 10 illustrates the influence on the TH’s overall fish resources, though an establishment of one more advanced fish sanctuaries was proposed at that time (Ahmed, 2013). Moreover, a significant number of fish protection katha were also established in different beels of the TH wetland, in which the estimated area was about 0.50 acre (Ahmed, 2011). So, we can recognize it as fish sanctuary.

Therefore, establishment of the fish sanctuary exhibited a positive impact in terms of overall fish production of this haor system. However, the positive impact of these management systems was limited to a few local communities, wherein the people living a little far from the TH are still remaining away from its core benefits (Alam et al., 2015). Unfortunately, this is because of the poor wetland resource governance systems, which also indicates a very critical issue now-a-days (Newaz and Rahman, 2019). In this situation, the community based co-management system was considered as the sustainable natural resource management through advancing all the local stakeholders (Islam et al., 2015; Newaz and Rahman, 2019). However, several studies (Ahmed, 2011; Alam et al.,

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**Table 9. Factors influencing the income of the fishermen (Tikadar et al., 2022).**

| Explanatory variables (Dependent variable – Log of monthly income) | Tanguar Haor | Hakaluki Haor | Overall |
|---------------------------------------------------------------|--------------|---------------|---------|
| Age (years)                                                   | 0.008**      | 0.008**       | 0.007***|
| Fish catch (kg/day/person)                                    | 0.124***     | 0.137**       | 0.144***|
| Level of education (year of schooling)                        | -0.011       | 0.006         | -0.003  |
| Family size (number)                                          | -0.025       | 0.019         | -0.002  |
| Participation of women in work (0 – no, 1 – yes)              | 0.103        | -0.109        | -0.005  |
| Training activities (0 – no, 1 – yes)                         | 0.473***     | 0.502***      | 0.500***|
| NGO membership (0 – no, 1 – yes)                              | 0.194**      | 0.305**       | 0.206***|
| Observations (n)                                              | 60           | 60            | 120     |
| R2                                                            | 0.531        | 0.459         | 0.4656  |

*Note: ***, **, * indicate the significance level at 1%, 5% and 10%, respectively.*

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**Table 10. Status of fish sanctuaries established in Tanguar Haor under the CBSMTH Project in 2011 (Ahmed, 2011).**

| Rank | Name of the fish sanctuary | Name of the katha materials | Impact in (case of production) |
|------|-----------------------------|-------------------------------|--------------------------------|
| 1    | Rupaboi beel Fish Sanctuary | Hjol, bamboo, other tree branches | Rui, Cita and Puti increased |
| 2    | Rowa beel Fish sanctuary    | Hjol, bamboo, bamboo roots    | 40% increased, increased brood fish |
| 3    | Tekunma beel Fish Sanctuary | Hjol, bamboo, bamboo branches | Different fishes increased |
| 4    | Ballardubi beel Fish Sanctuary | Hjol and Bamboo | Different fishes increased |
| 5    | Alamer Duar River Fish Sanctuary | Hjol and Bamboo | Chital, Pabda, small Snails increased |
have discussed about the TH considering the biodiversity status, socio-economic evaluation etc., therefore, a very few studies have disclosed the management system of the TH. Hence, Newaz and Rahman (2019) conducted a unique study on the TH in light of the three-phase cycle (2006–2016) of the CBSMTH project, in which the findings demonstrated that the initiative of developing community-based resource management remains a critical task in the TH. Besides, the ineffectiveness of these community systems largely due to the high dependency on resources, lack of guidance at the rural level etc., which is also responsible for poor management strategies (Newaz and Rahman, 2019). Therefore, it would be more clear to discuss the assessment with other Ramsar sites outside Bangladesh by Baker et al. (2021) in Canada. Canada ratified the Ramsar Convention in 1981, and although it went into active in 1975. About 37 Ramsar sites have been identified by Canada since that time (Baker et al., 2021). Therefore, the effectiveness of co-management structures, current management plans, and monitoring agendas were among the sustainability indicators used to evaluate each site. These indicators were created based on the Ramsar Convention Strategic Plan 2016–2024 and the 14 main areas of focus (Baker et al., 2021). Regarding management plans, governance frameworks, and reporting practices at several sites, the assessment results were highly variable. Thus, they had explained that the inadequate monitoring and reporting procedures and outdated management plans were the causes of variation (Baker et al., 2021).

Furthermore, it is certainly unfortunate that the effective sustainable co-management remains a difficult task in the TH, due to the high dependency of resource harvesters on the wetland ecosystems (Newaz and Rahman, 2019). Additionally, any co-management structure must go through a common process of learning by doing, experiencing success and failure along the way, and then undergoing continuous evaluation and development. However, given the previous experiences of both success and failure, government interventions and a coordinated effort by the local community should be sustained for the consolidation of the current governance framework in TH Addressing the needs of the growing human population will be another critical issue for TH fisheries management in the future. Hence, locally appropriate adaptive measures are required to address the social, environmental, and climatic challenges. Robust synchronization among government relevant line agencies, development actors, and stakeholders will be a future direction for addressing these challenges, sustaining the ecosystem, and conserving this rich fish biodiversity (Alam et al., 2015).

3.6. Research gap

The fundamental constraint of this study was that we had to overlook features of communities and their surroundings because our analyses were based on the broad conclusions of published studies. Several generalizations were made. First, because the studies employed various methods/years to assess the status of fish biodiversity, it was unable to make a direct comparison of fish diversity. Second, even if multiple topics were mentioned in the same article, each article was assigned to only one principal theme. For example, we regarded TH to be the key area of interest in most studies conducted in TH. We drew the same conclusions about TH’s various study areas. Finally, there was no effective framework in place to protect TH’s fish biodiversity and natural resources. As a result, the fishing community’s financial situation remained unchanged. Finally, while we are confident that the 22 peer-reviewed publications we covered are a fair and representative sample, due to accessibility and time limits, there were obviously omissions.

3.7. Recommendations for future management

The TH’s natural resources, particularly its fishery resources, are very much important to the local community, particularly the fisherman (Alam et al., 2015). In this context, the community-based fisheries management can benefit to preserve and intensification of this natural resources. However, an effective co-management system mostly takes time to unite the community governments through creating awareness and trusts, building local capacity, preserving informal entree of the poor to resources by creating an effective leasing systems and so on (IUCN Bangladesh, 2015b; Newaz and Rahman, 2019). In this situation, the management and maintenance of this wetland environment necessitates immediate attention from the appropriate authorities.

However, some specific points are strongly recommended here for the proper management of TH-

✓ Increase active participation of the local community to manage Haor fisheries through community motivation and awareness building;
✓ Establish a balanced approach tactic of fishing by fishing restriction in different fishing grounds and time;
✓ Encourage the use of science-based co-management by making sure that traditional and technological knowledge is incorporated into national policies and wetland management plans to ensure benefits of all resource harvesters;
✓ To strengthening the alternative livelihoods-advancement of effective eco-friendly tourism, formation of various income generation activities accompanying with the new market creations, extension of the Vulnerable Group Feeding (VGF) program for the fishers etc. can be considered as an effective management options as well.

General recommendations-

✓ Establishment of more effective fish sanctuaries along with the fish protection katha in several parts of the TH system;
✓ Develop an early warning system for flash floods in the Haor Basin to decrease damage caused by sudden flood;
✓ Hijal, koroch, and other varieties of trees needed to restore for the biological balance of the Haor Basin and protect homesteads areas;
✓ More study should be done on the Haor economy and ecology, with an emphasis on identifying problems in various dimensions and exploring prospects in the relevant domains for pragmatic and urgent policy consequences;
✓ Government policy and inter-departmental linkage should be well updated and representative to reduce the detrimental effects of ecotourism considering the sustainable haor management, as it is barely accepted from the unwanted influence;
✓ Lastly, prepare a master plan for the overall development of Haors, incorporating all areas such as water resources, fisheries, forestry, wetland management, and khas land allocation.

4. Conclusion

The largest wetland area in Bangladesh, TH is home to a wide variety of fish, reeds, algae, and aquatic plants and vegetation. The most clear conclusion regarding correlating trends with fish diversity declines is that it is not possible to identify which parameters exert which influences as multiple drivers are likely in play. As a result, fish diversity is under severe threat of gradual depletion. Several haor management policies and programs have been established by the government and non-governmental organizations, however these are not long-term solutions for haor management due to lack of proper empowering system and awareness of local fishermen. Thus, social recognition, government policy and strategy, nongovernmental activities, and community-based action are all crucial for the conservation of haor biodiversity. This review outlined the research gaps in TH that need to be taken into account in future studies for the sustainable management of TH’s fishery resources. We hoped that the findings of this study would be beneficial to a variety of stakeholders, including the fishing community, local managers, legislators, and TH management authorities. Furthermore, we wish to encourage the national and international communities to organize thorough surveys to evaluate the significance of TH before it undergoes irreparable damage.
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